

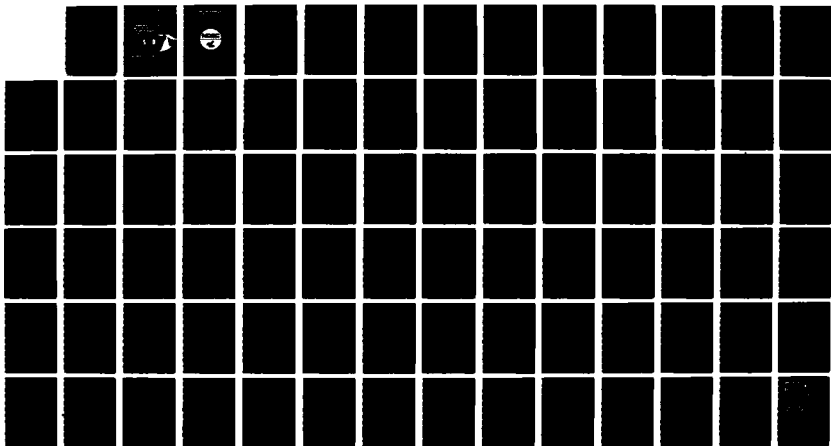
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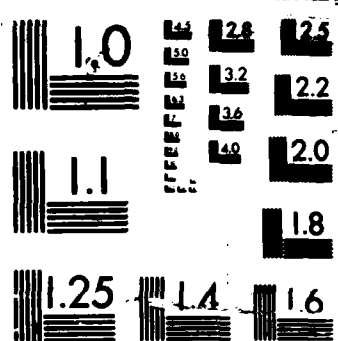
THE SEGMENTED WAVEGUIDE PROGRAM FOR LONG WAVELENGTH  
PROPAGATION CALCULATIONS(U) NAVAL OCEAN SYSTEMS CENTER  
SAN DIEGO CA J A FERGUSON ET AL APR 87 NOSC/TD-1871  
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MICROCOPY RESOLUTION TEST CHART

Technical Document 1071

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# The Segmented Waveguide Program for Long Wavelength Propagation Calculations

J. A. Ferguson  
F. P. Snyder

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**Naval Ocean Systems Center**

San Diego, California 92152-5000

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**E. G. SCHWEIZER, CAPT, USN**  
Commander

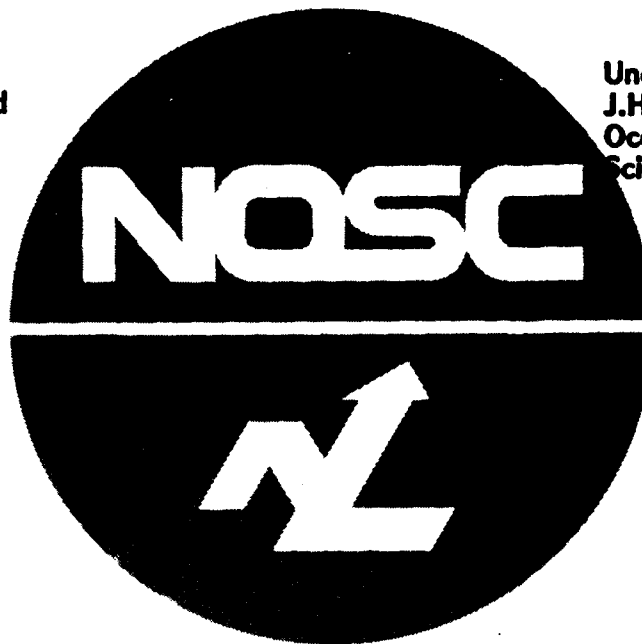
**R. M. HILLYER**  
Technical Director

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## INTRODUCTION

The model of longwave propagation developed at the Naval Ocean Systems Center (NOSC) is based on a waveguide mode formulation. To determine signal levels in this approach the basic problem is to obtain the modal solutions to the specific waveguide under consideration (Pappert et al., 1970, Morfitt and Shellman, 1976), where complicated propagation paths are divided into horizontally homogeneous segments. The parameters of the segments are determined by the earth's ground conductivity, the magnitude and orientation of the geomagnetic field with respect to the direction of propagation, and the state of the ionosphere. Well-known computer programs which make the necessary calculations for a single set of propagation parameters are "WAVEGUID" (Pappert et al., 1970) and "MODESRCH" (Morfitt and Shellman, 1976). The WAVEGUID computer program and related programs are described in a series of reports and familiarity with the important elements of this series is assumed (Pappert, Gossard and Rothmuller, 1967; Sheddy et al., 1968; Pappert, Moler and Shockey, 1970; Morfitt and Shellman, 1976). This report describes a modified version of that program designed to supply calculations of long wavelength propagation along segmented propagation paths. This program is called the Segmented Waveguide (SW).

The computer program obtains waveguide mode solutions for very low frequencies and low frequencies (VLF/LF). The program allows for multiple homogeneous segments to be specified, allowing for consideration of variations in the earth-ionosphere waveguide. Path geometry and geophysical parameters can be computed by the program. Ionospheric disturbances due to man-made or naturally occurring events can also be modeled using the program.

*Essential features of this program include:*

- Automatic segmentation of the propagation path
- Allowance for presegmentation of the propagation path
- Allowance for variation of the ionosphere along that path

The program operates on propagation paths defined by a transmitter location and either a direction or a receiver location. A propagation path is defined as the great circle on a spherical earth. Variation of the geophysical parameters are to be expected along realistic paths. The diurnal condition in large part determines the significance of the other parameters. For instance, under daytime conditions the effect of variation of the geomagnetic field along a path is usually not significant to the resulting mode parameters. The program incorporates routines for calculating the parameters of the geomagnetic field and for selecting the ground conductivity at any point on the earth's surface.

Each of the path segments is treated as a horizontally homogeneous planar waveguide. Earth curvature is introduced by use of a modified refractive index. A set of possible solutions to the waveguide mode equation must be input. Each of these solutions is processed by an iteration routine. Each iteration requires computation of ionospheric and ground reflection coefficients. Calculation of the ionospheric reflection coefficients requires integration of the coefficients through the ionosphere. An approximate formulation may be used which requires a secondary set of complex angles be specified by the user. In that case, the ionospheric reflection coefficients are calculated for the secondary set of angles. These coefficients are used to interpolate the ionospheric reflection coefficients during the iteration of the primary set of possible solutions. This interpolation procedure requires much less computation time than does the more exact procedure.



The set of solutions for the first homogeneous segment must be input by the user. The program uses the results of up to three consecutive segments to extrapolate the solutions for successive segments. This reduces the number of iterations which are required for subsequent segments and allows for the tracing of mode solutions through a wide range of path variations.

The primary output of "SW" is data which may be used in mode summing programs. The strength of the electromagnetic field along the path can be obtained with either of two mode conversion models, one denoted "FULLMC" (Pappert and Shockey, 1972) and the other denoted "FASTMC" (Ferguson and Snyder, 1980). "FULLMC" does integrations through the ionosphere prior to calculating mode conversion coefficients and can be quite slow in execution time whereas "FASTMC" avoids the transionospheric integrations by use of approximations and runs quite quickly.

### PROGRAM CONTROL

Program execution is controlled by strings containing mnemonic words. These strings and the sequence of operations initiated by them are described below. These control strings, as well as variable names and names of subroutines, appear in upper case. For clarity, the control strings are enclosed in single quotes and names of subroutines are enclosed in double quotes. Table 1 summarizes these control strings.

Table 1. Summary of control strings.

ID	run identification
NAME	general NAMELIST data
EIGEN	alternate EIGEN list input
PROFILE i	ionospheric specie profiles (i is 1 or 3)
COLFREQ	ionospheric collision frequency profiles
COORD	automatic segmentation of propagation path
PRESEG	presegmentated propagation path
QUIT	end of job

'ID' indicates that the next line of data to be read is a general identification for the path under consideration. This identification appears in the printout. It is also written to the mode parameter output file.

'NAME' initiates the reading of general program data via the NAMELIST: DATUM. Table 2 lists all variables, their type (I indicates integers, R indicates real (floating point) variables, C indicates complex variables), their units where applicable, and their initial values. If a variable defines an array, then the dimension of the array follows the name in parentheses. The NAMELIST input format is quite flexible but requires that column 1 be blank. Variable names are followed by an equal sign and then by the value of the variable. Array variable names may be followed by a string of values separated by commas and/or spaces. Embedded blanks are not allowed in the variable names. Variable types must be considered; for example, values for integer variables may not contain decimal points, but values for real variables do not have to have decimal points. Logical variables may be specified with any of '.true.' '.t.' 't' '.false.' '.f.' 'f'. The values of character variables must be enclosed within quotes. The first record of the NAMELIST input must contain ' &name ' where 'name' is the

NAMELIST name (in this case, DATUM). The end of the NAMELIST is indicated by '&end'. Some of the values to be found in the following text are of the form  $A(N)$  to indicate  $A$  to the power  $N$ .

'EIGEN' allows for input of the list of trial solutions to be made from a file. The format of the input is the same as with NAMELIST. The control string is followed by the name of the file (starting in column 9) containing the NAMELIST data. The source of these input solutions could be a previous run with the program or from one of the automatic mode searching programs such as the one described by Morfitt and Shellman (1976).

'PROFILE i' initiates reading of the ionospheric charged particle profile data used to model the upper boundary of the earth-ionosphere waveguide. The value of  $i$  indicates the number of ionospheric species to be used and it must have one of two possible values: 1 is for electrons only and 3 is for electrons and ions. If  $i$  is not specified, a value of 1 is assumed. The use of  $i$  is shown below. The 'PROFILE i' string is immediately followed by a single line of identification for the profile. The profile is input starting at the top of the ionosphere using a formatted input. Each line contains the height in km, the electron density at that height in electrons per cubic centimeter, and if ions are to be considered, the positive ion density at that height in ions per cubic centimeter. The height is in columns 1-7 and the electron and ion densities are required to be in columns 14-21 and 24-31, respectively. The end of the profile is indicated by a dummy height with value less than zero. A maximum of 50 heights may be used. If  $i$  is 1, then only the electron density is read. Consequently, only the electron density need be present in the data. If  $i$  is 3, then the electron and positive ion densities are read and the negative ion density is computed by subtracting the electron density from the positive ion density (to preserve charge neutrality).

In the integration of the reflection elements through the ionosphere the program interpolates exponentially between input heights. The profile should contain sufficient data to define the ionospheric structure with height. For example, an exponential profile should consist of only the top and bottom heights and densities. Many regularly spaced heights tend to slow the integration.

A purely exponential conductivity profile (electrons only) may be input via the NAMELIST variables BETA and HPRIME.

Additional specie parameters are needed for the waveguide mode computations and are described below.

'COLFREQ' initiates reading of an ionospheric collision frequency profile. This allows use of nonexponential collision frequencies. The 'COLFREQ' string is immediately followed by the collision frequency profile, starting with the highest height and ending with a dummy height of value less than zero as in the case of specie profile described above. These heights need not match those used under 'PROFILE i'. The format of the data is the same as used for 'PROFILE i' except that collision frequencies for all species must be input since the negative ion collision frequency cannot be simply computed from the other two. If only electrons are being used, then only that collision frequency need be present. As with the specie profiles, the program interpolates exponentially between input heights.

An exponential collision frequency specification may be input via the NAMELIST variables EXPNU and COEFNU.

'COORD' initiates automatic segmentation of the propagation path. This string must be placed after all pertinent data have been read. This option is best applied to simple cases such as all daytime. The basic input consists of the path specification, the environment, and the starting mode solutions.

'PRESEG' allows for previously determined segments to be used along the propagation path. This option requires most of the same inputs as 'COORD' except that the user supplies the distances at which segments begin. At each segment the user has the option of specifying the parameters of the geomagnetic field, the ground and the ionosphere.

## CALCULATION OF MODE PARAMETERS

The inputs to the mode equation computations are supplied by geophysical routines and/or by the user. The subroutine which controls the calculations is "WVGUID". Most user supplied data values are input to the program via NAMELIST. These parameters are summarized in table 2 and are discussed in more detail below. In table 2 the data types are Integer (I), Real (R), and Complex (C).

Table 2. NAMELIST Inputs.

Variable	Type	Default	Description
FREQ	R	0.0	Frequency in kHz
RHO	R	0.0	Distance from the transmitter of the current segment in Mm.
AZIM	R	0.0	Magnetic azimuth angle in degrees east of magnetic north.
CODIP	R	0.0	Magnetic co-dip angle in degrees.
MAGFLD	R	0.0	Intensity of the geomagnetic field in Webers/square meter.
SIGMA	R	4.64	Ground conductivity in Siemens/meter.
EPSR	R	81.0	Dielectric constant of the ground.
BETA	R	0.0	Slope of the exponential profile in km(-1)
HPRIME	R	0.0	Reference height of the exponential profile in km.
TLONG,TLAT	R	0.0,0.0	Transmitter coordinates in degrees
RBEAR	R	720.0	Geographic bearing of the path in degrees
RLONG,RLAT	R	0.0,0.0	Receiver coordinates in degrees
DRMIN	R	0.125	Minimum distance step size in Mm
DRMAX	R	0.5	Maximum distance step size in Mm
DMAX	R	20.0	Maximum distance in Mm
YEAR	I	0	Year
MONTH	I	0	Month number with January being 1
DAY	I	0	Day of the month
GMT	R	0.0	Greenwich meridian time in hours
NPRINT	I	1	Flag used to control the amount of print out
NPROF	I	1	Flag to indicate which form of the profile is to be used

MIDPNT	I	0	Flag to indicate that only the midpoint is to be considered
IGCD	I	0	Flag to indicate that the computed distance between the transmitter and receiver is to be used
IGND	I	0	Flag to indicate that the ground conductivity is to be determined from the ground map
MDIR	I	0	Flag used to reverse the direction of the magnetic field
EIGEN(60)	C	0.0,0.0	Initial solutions for the waveguide modes in degrees.
TLIST(30)	C	0.0,0.0	Angles where the reflection coefficients are computed for the inexact interpolation routine in degrees
DTHETA	C	0.01,0.001	Change in the mode solution used to define the iteration in degrees
LUB	C	0.05,0.005	Tolerance used to test the differential change in the mode solution. Used to stop the iteration
DEIGEN	C	0.05,0.005	Tolerance used to define duplicate modes in degrees
FTOL	R	1.0	Tolerance used to determine if the mode equation has been satisfied by the solutions
THTINC	R	0.5	Maximum change in degrees of either the real or imaginary part of the mode solution from one iteration to the next
MAXITR	I	7	Maximum number of iterations to attempt
ALPHA	R	$3.14 \times 10^{-4}$	The earth curvature correction factor in $\text{km}^{-1}$
H	R	50.0	Height at which the modified refractive index is unity in km
D	R	0.0	Height at which the integration through the ionosphere is stopped in km
PREC	R	2.0	Factor which controls the precision of the reflection coefficient integration
WR0	R	$2.5 \times 10^5$	Value of $\omega_{pr}$ used to define the reference height
ATNMAX	R	50.0	Maximum attenuation rate of modes to be retained in dB/Mm
DEBUG	I	0	Flag used to generate additional printout for debugging purposes
TYPITR	I	0	Flag used to define the form of the mode equation
RPOLY	I	1	Flag used to define the reflection coefficient calculation
NRTLST	I	5	Number of points to use in the interpolation of the reflection coefficients during inexact iterations
LUNIT7	I	7	Logical unit number to which the mode parameters data are output
CHARGE(3)	R	-1.0, 1.0,-1.0	Charge of the ionospheric species
MRATIO(3)	R	1.0, $2 \times 5.8 \times 10^4$	Ratio of the mass of the ionospheric species to that of electrons
COEFNU(3)	R	$1.816 \times 10^{11}$ , $2 \times 4.54 \times 10^{10}$	Collision frequency of the ionospheric species at the ground in collisions/sec
EXPNU(3)	R	-0.15, $2 \times -0.15$	Exponential slope of the collision frequency in $\text{km}^{-1}$

The radio frequency in kHz is specified by the variable **FREQ**. The input to subroutine "WVGUID" includes an ionospheric profile. The variable **NPROF** controls which ionospheric profile is to be used. A value of 0 indicates that the profile input via 'PROFILE i' is to be used. A value of 1 indicates that an exponential electrons only profile is to be used. The profile is specified by the exponential slope **BETA** in  $\text{km}^{-1}$  and a reference height **HPRIME** in km (Wait and Spies, 1964). A value of 2 for **NPROF** is used to indicate that a series of profiles will be input. This option only applies to 'PRESEG'. The profiles are to be input using the same format as described under 'PROFILE i', including the control string. There must be a profile for each segment.

Additional specie parameters are needed. The number and order of these specie parameters must be consistent with the charged particle densities of 'PROFILE i'. The charges of the species are input as **CHARGE** (i.e., **CHARGE** = -1, +1, -1). The masses of the species relative to that of an electron are input as **MRATIO**. The collision frequencies may be defined with 'COLFREQ' (nonexponential) or with the variables **COEFNU** in collisions per second and **EXPNU** in  $\text{km}^{-1}$ . The collision frequency  $\nu$  at an altitude  $z$  is then defined by

$$\nu = \text{COEFNU} * \exp(\text{EXPNU} * z)$$

where  $z$  is in km.

Parameters of the geomagnetic field are specified by **AZIM**, the angle between magnetic north and the direction of propagation in the horizontal plane measured in degrees east of north, **CODIP**, the magnetic co-dip angle measured from the vertical (i.e., the north pole has a **CODIP** of 0), and **MAGFLD**, the magnetic intensity in Webers per square meter or in Gauss. The magnitude of **MAGFLD** is tested. If it is greater than  $10^{-2}$  then the input value is assumed to be in Gauss and is multiplied by  $10^{-4}$ .

**MDIR** is a flag that when set to 1, causes the direction of propagation as input to be reversed. This allows for development of a data set appropriate to examining transmitter deployment.

Ground conditions are specified by **SIGMA**, the conductivity in Siemens/m, and **EPSR**, the relative dielectric constant.

The presegmentation option allows the magnetic field and ground parameters to be varied by the user.

The correction for earth curvature is controlled by **ALPHA** in  $\text{km}^{-1}$  which is defined as  $2$  over the radius of the earth. For a curved earth **ALPHA** is  $3.14 \times 10^{-4} \text{ km}^{-1}$  and for a flat earth **ALPHA** is 0.

Ionospheric altitude parameters are **H**, which is the height in km at which the modified refractive index is unity and is the height to which the mode solutions are referenced; **D**, which is the height in km below which ionospheric effects can be ignored. **D** must be equal to or greater than the bottom height of the ionospheric profiles used. It is usually sufficient to choose **H** equal to **D**. The choice of **D** and **H** is also discussed by Pappert et al. (1967).

The trial eigenangles follow the variable name EIGEN which is a complex variable. Up to 60 eigen angles may be input. If little is known about the expected solutions for a given set of conditions, a set of approximate solutions may be obtained using a TLIST. The TLIST is a list of as many as 30 complex angles which are used to set up an interpolation matrix of the ionospheric reflection elements (Sheddy et al., 1968). The program then uses this matrix to interpolate reflection elements during the iterative process used to obtain mode solutions. These solutions are referred to as "inexacts" in order to distinguish them from the more accurate solutions using integrated reflection coefficients. The variable NRTLST determines the maximum number of TLIST angles used in each interpolation. During the inexact iteration process, the program computes the magnitude of the complex difference between the current value of the solution and each of the TLIST angles. The program orders the TLIST angles from the smallest to the largest difference and selects the first NRTLST of them to be used in the interpolation. This improves the accuracy of the interpolated reflection coefficients and reduces the number of terms used.

If more than 30 EIGENs are input, then the program sorts the angles according to their attenuation rate and deletes those with attenuation rates greater than a user specified maximum. The initial value of this maximum is ATNMAX. If there are still more than 30 angles, then the maximum attenuation rate is reduced by 5 dB/Mm and the input list is sorted again. This process is repeated until there are less than 30 angles in the list.

If the number of EIGEN or TLIST inputs varies from one NAMELIST to the next, then each EIGEN or TLIST list should be terminated with a zero. If RPOLY is not 0 and the first value of TLIST is 0, then TLIST is set equal to the first 30 EIGENs.

The Newton-Raphson iteration process, used to find the eigenangles which satisfy the modal equation is described by Sheddy et al. (1968). Iteration is performed for each input EIGEN. The iteration stops when the maximum number of iterations (MAXITR) is exceeded or when the change in the real and imaginary parts of the solution is calculated to be less than the real and imaginary parts of LUB, respectively.

The type of solution obtained is determined, in part, by RPOLY, which can have three values: 0 for exact solutions only, 2 for inexact (approximate) solutions only, and 1 for inexact computed and used as inputs to obtain exact solutions. The use of RPOLY equal to 1 is described more fully below.

The flag TYPITR is used to obtain vertically polarized modes only (TYPITR equal to 1) or horizontally polarized modes only (TYPITR equal to 2). It is physically meaningful to apply this option only for nearly isotropic conditions, no magnetic field (MAGFLD set to 0), or east to west and west to east propagation at the geomagnetic equator (CODIP is 90 and AZIM is 90 or CODIP is 90 and AZIM is 270).

To ensure consistent mode sums and eliminate redundant solutions, each exact and inexact EIGEN solution is tested for several conditions. The first is that the imaginary part of the solution must be less than zero in order to have attenuating modes. The second is that the magnitude of the modal equation must be less than FTOL. This parameter is tested only for final solutions and only if the number of iterations required to obtain the solution is greater than or equal to MAXITR. It is generally true that if the iteration stops because the change in the mode solution is less than LUB, then the value of the mode equation is small. There are instances in which the test on FTOL will still fail. Consequently, the value of FTOL is set very high in order to allow the

program to continue execution. In some cases the user may want to modify the default value in order to perform special tests. If RPOLY is 1, the inexact results are treated as intermediate results. The third test is that the value of the EIGEN solution must be different from all previous solutions by an amount DEIGEN which is input as a complex number. The real and imaginary parts of DEIGEN are the tolerances for the real and imaginary parts of the EIGEN solutions, respectively. If one of the above tests results in a mode being dropped from the list of solutions, then the program follows the procedures outlined below under the discussion of mode tracing.

Subroutine "WVGUID" computes and prints attenuation rate in dB/Mm, phase velocity relative to the speed of light, the magnitude, and phase of Wait's excitation factor (Wait, 1962) at the ground in dB and radians.

The headings for the number of iterations to go from the input angle to the final solution, the final solution, the magnitude of the modal equation, and the magnitude of the polarization mixing ratio are printed as ITER, EIGEN, MAG F, and MAG P, respectively. The attenuation rate, phase velocity relative to the speed of light, magnitude, and phase of Wait's excitation factor, and the final solution references to the ground are printed under the headings of ATTEN, V/C, WAIT'S EXC, and THETA', respectively.

The parameters YEAR, MONTH, DAY, and GMT are used only to pass the values to the output files. These parameters are useful for helping to identify the output data to programs which may use this information.

## **PATH CALCULATIONS**

These calculations are controlled by "GCPATH". They can be divided into three classes. The first automatically computes geometry and geophysical parameters which are obtainable from just the location of a point on the propagation path or uses presegmented distances and geophysical parameters. In addition, the program extrapolates the EIGEN list and TLIST so as to trace modes along a path.

## **PATH GEOMETRY**

All geometry calculations are for a spherical earth. Inputs to this portion of the program consist of transmitter and receiver locations, path length, and path increments. Transmitter and receiver longitude and latitude are input with TLONG and RLONG and TLAT and RLAT. The convention used in the program is east longitude and south latitude are negative. An alternate input for the receiver position is its bearing, RBEAR, in degrees east of north. In the execution of the program RBEAR is tested. If RBEAR is 720, then the program uses RLONG and RLAT to define the path. If RBEAR is not 720, then it and the input path length, DMAX, are used to define the path. DMAX is specified in megameters and must be less than or equal to 20. If RLONG and RLAT are used, there are two path lengths possible. If the parameter IGCD is equal to 1, the path length is set equal to the computed short great circle distance between the transmitter and receiver. If IGCD is equal to 0, the path length is unchanged from what was input (DMAX). If the path bearing is input, the path length is always DMAX.

The starting value of the distance from the transmitter is input as RHO and is in Mm. The path increments are controlled by the mode tracing results and the variables DRMIN and DRMAX which are all in units of Mm. The procedures of the values are described as follows.

The geomagnetic field is computed at the first path point defined by RHO and at the beginning of each path segment. The ground conductivity and relative dielectric constant are specified by the user through SIGMA and EPSR via NAMELIST or by searching the ground map. If IGND is 0, the ground map is not searched and ground conditions are assumed constant, as input, for the entire path for 'COORD' or as varied by the user for 'PRESEG'. If IGND is 1, the DECO-NRL 10 level ground conductivity map (Hauser, Garner, and Rhoads, 1969) is searched for the appropriate values of SIGMA and EPSR at the beginning of each path segment.

If the value is assumed that the entire propagation path can be described adequately by the conditions at the midpoint of the path, then the path conditions at that point can be obtained if MIDPNT is set to 1. The subsequent modal calculations will then be for the midpoint conditions.

At the transmitter and at the end of each path segment, the parameters to be used in the "WVGUID" calculations are printed next to the heading, PROPAGATION PATH PARAMETERS, as described below. In addition, the distance in megameters from the transmitter, the coordinates and the geographic bearing of the path at the current point are printed under the headings RHO, LAT, and BEAR, respectively. If the midpoint option is being used, then the above information for the midpoint is printed.

## PRESEGMENTATION

In some instances, user segmentation of the propagation path is desired. The control string 'PRESEG' allows arbitrary segmentation of the path. This is accomplished by a succession of data lines in list directed format containing values for path distance in Mm, AZIM, CODIP, MAGFLD, SIGMA, EPSR, BETA, and HPRIME, respectively. List directed input is accomplished by entering values separated by commas or spaces. There must a data entry for each request in the input list. If a value is not to change from one data line to the next, then the value need not be entered but its omission must be indicated by a pair of commas. The first value of path distance need not be zero. The presegmentation is terminated by a distance value of 40.

If NPROF is 0, the ionospheric profile is constant for the path and is defined by 'PROFILE i'. If NPROF is 1, then the values of BETA and HPRIME on the presegmentation data lines are examined. If BETA is zero, then the previously defined values of BETA and HPRIME are used. The latter may be input via NAMELIST so that a constant ionosphere for the path can be obtained by using NAMELIST input. If either of the values of BETA and HPRIME are to change, both must be input. If NPROF is 2, then each presegmentation data line must have a corresponding 'PROFILE i' profile specification on logical unit 3.

The following conventions are used for using the values of the presegmentation data. If the value of MAGFLD is zero or blank, then the magnetic field parameters are calculated. If a nonzero value is specified, then all of the magnetic field parameters are taken from the presegmentation data. If constant magnetic parameters are desired along the path, the values must be specified on each presegmentation data line. If the value of SIGMA is not entered, then the previously specified value of SIGMA and EPSR are used. Otherwise, the values of these parameters are taken from the presegmentation data line. Constant values for the whole path may be specified via NAMELIST or in the first presegmentation card. If IGND is 1, then the ground



map is searched and the values of SIGMA and EPSR on the cards are ignored. If BETA is not entered, the currently defined values are used for the electron density profile. Even if only one value in the pairs SIGMA, EPSR, and BETA, HPRIME is to be changed, both values must be specified.

## MODE TRACING

Efficient computation of mode parameters along the propagation path is best achieved by using RPOLY set to 1, which will be assumed for the rest of this discussion. At the first point on the path, solutions are best obtained by using a TLIST composed of angles which are believed to be approximately correct and an EIGEN list of many regularly spaced angles such as 88, -1, 87, -1, 86, -1, etc. Alternatively, the EIGEN list should be the list of approximately correct solutions with the TLIST set to zero or the 'EIGEN' control string could be used to specify solutions from some other source. The program computes inexact solutions for the conditions at the first point on the path. After exhausting the EIGEN list, obtaining inexact solutions, and deleting of those failing the tests discussed above, exact solutions are computed using the results of the inexact.

Now the discussion must be separated for the two-path segmentation options. For the 'COORD' option, the second point on the path is DRMIN from the transmitter. For this point, the final solutions for the first point are placed in both TLIST and EIGEN and the same process of calculation of inexact and exacts is repeated. If DRMIN is not too far from the transmitter and/or the geophysical parameters do not change too much, then this step in the extrapolation process is quite efficient. Now the program has two sets of final solutions and makes a linear extrapolation for TLIST and EIGEN angles for the third point on the path which is twice DRMIN from the transmitter. The sequence of calculations for the inexact and exact solutions is repeated. For the fourth and all subsequent points on the propagation path, the program uses the previous sets of final solutions to make second order extrapolations for TLIST and EIGEN angles. The distance increments are chosen as described below.

As the program steps out along the propagation path, modal solutions may be lost or removed. First, a mode may be lost in the screening process in subroutine "WVGUID" as described above. At the first point on the path, modes may be overlooked simply because of lack of adequate trial solutions and/or more than one EIGEN input resulting in the same final solution, perhaps due to closely spaced input EIGEN values. If computations are being made at the transmitter or at the midpoint, it is acceptable to lose a solution from the input EIGEN list. At all other points, when a mode is lost execution terminates in "WVGUID". After the tests on the solutions in "WVGUID" are completed at the first point on the path, the program assumes that it has a complete set of modes. After this set is established, solutions may be acceptably removed only in the extrapolation subroutine, "EXTRAP". The solutions produced by "WVGUID" for the current segment are used to compute attenuation rates. Those solutions whose attenuation rate exceeds ATNMAX are deleted from the list. The location of the solution in the set is marked and its removal is indicated by a blank line in the printout of solutions produced by subsequent "WVGUID" calculations.

If a mode is lost during "WVGUID" calculations, the path point is moved back to about halfway between the current point (where a solution was lost) and the previous point (where all solutions were obtained). The actual distance depends on the current value of the distance increment. If the increment is greater than DRMIN, then the

new increment is chosen that it is an integral multiple of DRMIN and is less than or equal to half the previous increment. Geophysical parameters at the new path point are computed, the EIGEN list is revised by "EXTRAP", and "WVGUID" calculations are repeated.

If no modes are lost and the number of iterations required to obtain the solutions is less than or equal to half of MAXITR, then the distance increment is increased by DRMIN. This increase in the distance increment can continue until the path increment is equal to DRMAX. If no modes are lost and the number of iterations required to obtain the solutions is greater than half of MAXITR, the path increment is decreased by DRMIN.

If modes are lost and the separation between the previous point (for which all modes were found) and the current point (for which modes were lost) is less than or equal to DRMIN, then the distance increment is halved. The geophysical parameters for the new path point are linearly interpolated using the parameters of the two points at which geophysical parameters were computed, the EIGEN list is revised by "EXTRAP", and "WVGUID" calculations are repeated. Solutions obtained for interpolated path points are not saved. They are used only to trace the mode solutions between the points for which the geophysical parameters are computed.

If no modes are lost and the number of iterations required to obtain the solutions is less than or equal to half of MAXITR, then the distance increment is doubled. This increase in the distance increment can continue until the path increment is equal to the distance to the end of the interpolation interval. If no modes are lost and the number of iterations required to obtain the solutions is greater than half of MAXITR, the path increment is halved. If the new distance increment is less than 15 km, then the program aborts.

For the 'PRESEG' option, the distance increment is controlled by the intervals between the presegmented distances. When modes are lost, the interpolation procedure for cases in which the backup interval is less than DRMIN described above is followed.

## OUTPUT

Mode parameters from the program are written to the logical unit whose numerical value is LUNIT7. The first line of data written contains the transmitter location, path bearing, and the date and time, as input through NAMELIST. The identification which followed 'ID' is written next. If no identification was specified with 'ID', this line of data is blank. The identification is followed by a sequence of lines at each output distance.

The first line of data at each such distance contains the distance, frequency, AZIM, CODIP, MAGFLD, SIGMA, EPSR, and the reference height of the ionospheric profile. In descriptions of other programs, this first line of data at each distance is referred to as the RFACMSET header. This header line is followed by pairs of data lines, one pair for each mode. The quantities in these data lines are the mode solution as a complex angle in degrees, a flag, T1, T2, T3, and T4. The flag and the parameters T1, T2, T3, and T4 are described in detail by Ferguson and Snyder (1980). The last line of data at each output distance is blank. These data are suitable for use in "FASTMC" (Ferguson and Snyder, 1980).

If the program fails because of some problem at the first path point, it writes 'Failure at RHO 1' to logical unit 90. Otherwise, it writes the distance of the last point for which "WVGUID" successfully completed. If the end of the path is reached, then this distance is output as 40.

### SAMPLE INPUT

Sample input files are shown in figures 1 and 2. In the first sample (figure 1), the path is to be run for all nighttime conditions assuming all seawater ground. The EIGEN list for the transmitter is input directly and the automatic path segmentation is to be used.

```
id
Sample run
name
&datum freq=23.4 h=50 d=75 lunit7=7 atnmax=50
tlong=150 tlat=20 rbear=10 dmax=10
lub=.005 .0005 dtheta=.01 .001
deigen=.05 .005 thtinc=.05
beta=.43 hprime=87
eigen= 85.678 -0.206 84.595 -0.688 81.806 -0.609 81.027 -0.255
       77.653 -0.791 77.023 -0.269 73.199 -0.825 72.980 -0.300
       68.926 -0.264 68.599 -0.955 64.751 -0.213 63.907 -1.144
       60.457 -0.183

&end
coord
```

Figure 1. Sample input using COORD option.

The second example (figure 2) is a much more complicated case. It is for the same path of the first sample, but the ionosphere is to be varied according to the diurnal conditions along the path for July 15 at 1612Z. The transition from night to day has been modeled as five steps starting with BETA at 0.30 and HPRIME at 74 and ending with BETA at 0.43 and HPRIME at 87. In addition, the ground conductivity for the last profile takes on three values: 4, 10(-2), and 10(-3). In order to improve the efficiency of the mode tracing, additional segmentation has been performed so that each ground conductivity is processed separately. The segmentation does not produce final output that is monotonically increasing in distance from the transmitter. The necessary ordering of the segments must be performed by editing the final output file or by a user supplied program. The initial mode solutions for each segment have been already calculated and stored in a set of files named XMTR202.MFx where x ranges from 0 to 6.

```

id
Sample run
name
&datum freq=23.400 h=50. lunit7=7 atnmax=50.
lub=0.005 0.0005 dtheta=0.010 0.0010
deigen=0.050 0.0050 thtinc=0.05
year=84 month= 7 day=15 gmt=16.2
tlong= 158.150 tlat= 21.417 dmax=4
rbear=202.0 &end
eigen xmtr202.mf0
preseg
0.000,190.6, 50.8,0.350,4.E+00,81.,0.30,74.0,
40,0,0,0,0,0,0,0,
eigen xmtr202.mf1
preseg
0.500,190.8, 56.8,0.337,4.E+00,81.,0.32,76.2,
40,0,0,0,0,0,0,0,
eigen xmtr202.mf2
preseg
0.960,190.9, 63.1,0.329,4.E+00,81.,0.34,78.3,
40,0,0,0,0,0,0,0,
eigen xmtr202.mf3
preseg
1.040,190.9, 64.2,0.327,4.E+00,81.,0.37,80.5,
1.240,190.9, 67.3,0.325,4.E+00,81.,0.37,80.5,
40,0,0,0,0,0,0,0,
eigen xmtr202.mf4
preseg
1.340,190.9, 68.8,0.324,4.E+00,81.,0.39,82.7,
1.540,190.9, 72.1,0.323,4.E+00,81.,0.39,82.7,
40,0,0,0,0,0,0,0,
eigen xmtr202.mf5
preseg
1.640,190.9, 73.8,0.322,4.E+00,81.,0.41,84.8,
1.820,190.9, 76.8,0.322,4.E+00,81.,0.41,84.8,
40,0,0,0,0,0,0,0,
eigen xmtr202.mf6
preseg
1.940,190.8, 78.9,0.322,4.E+00,81.,0.43,87.0,
2.120,190.8, 82.2,0.323,4.E+00,81.,0.43,87.0,
2.300,190.7, 85.5,0.324,4.E+00,81.,0.43,87.0,
2.480,190.6, 88.8,0.326,4.E+00,81.,0.43,87.0,
2.660,190.6, 92.1,0.329,4.E+00,81.,0.43,87.0,
2.840,190.5, 95.5,0.333,4.E+00,81.,0.43,87.0,
3.020,190.4, 98.9,0.337,4.E+00,81.,0.43,87.0,
40,0,0,0,0,0,0,0,

```

Figure 2. Sample input using PRESEG option.

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- Sheddy, C. H., R. A. Pappert, Y. A. Gough, and W. F. Moler, "A FORTRAN Program for Mode Constants in an Earth-Ionosphere Waveguide", DASA Report 683, May 1968.
- Wait, J. R., *Electromagnetic Waves in Stratified Media*, Pergamon Press, New York, p. 221, 1962.

**APPENDIX: LISTING OF THE PROGRAM**

```

0001      c      SW: SEGMENTED WAVEGUID
0002      c
0003      include 'common1.for/list'
0004      1 c
0005      1      common/input/freq,rho,azim,codip,magfld,sigma,epsr,beta,hprime,
0006      1      $      hprout
0007      1      common/path/pathid,tlong,tlat,rlong,rlat,rbear,dmax,drmin,drmax,
0008      1      $      year,month,day,gmt,nprint,nprof,npath,igcd,ignd,mdir,lost,
0009      1      $      lunit7,lx
0010      1      common/ionosp/htlist(50),lnlist(50,3),hcllist(50),cflist(50,3),
0011      1      $      charge(3),mratio(3),nrspec,lhtmx,lhtmn,lht,mhtmx,mhtmn,mht
0012      1 c
0013      1      character*80 pathid
0014      1      integer year,day
0015      1      real*4 freq,rho,azim,codip,magfld,sigma,epsr,beta,hprime,hprout,
0016      1      $      tlong,tlat,rlong,rlat,rbear,dmax,drmin,drmax,gmt,
0017      1      $      htlist,lnlist,hcllist,cflist,charge,mratio
0018      1 c
0019      include 'common1.ini/list'
0020      1 c
0021      1 c      initialize common1
0022      1      data freq/0./,rho/0./,azim/0./,codip/0./,magfld/0./,
0023      1      $      sigma/4.64/,epsr/81./,beta/0./,hprime/0./,
0024      1      $      tlong/0./,tlat/0./,rlong/0./,rlat/0./,rbear/720./,
0025      1      $      dmax/20./,drmin/.125/,drmax/.5/,mdir/0/,
0026      1      $      year/0/,month/0/,day/0/,gmt/0./,nprint/1/,nprof/1/,
0027      1      $      igcd/0/,ignd/0/,mdir/0/,lunit7/7/,
0028      1      $      charge/-1.,1.,-1./,mratio/1.,2*58000./,nrspec/1/
0029      1 c
0030      include 'common2.for/list'
0031      1 c
0032      1      common/wg in/elist(2,30),tlist(2,30),dtheta(2),lub(2),deigen(2),
0033      1      $      thtinc,ftol,maxitr,alpha,h,d,prec,wr0,atnmax,debug,typitr,
0034      1      $      rpoly,nrtlst
0035      1      common/wg out/tp(30),tterm(4,30),nterm(30),mode(30),modes,nmds
0036      1 c
0037      1      complex*8 tp,tterm,dthta
0038      1      integer debug,typitr,rpoly
0039      1      real*4 elist,tlist,dtheta,lub,deigen,thtinc,ftol,alpha,h,d,prec,
0040      1      $      wr0,atnmax
0041      1 c
0042      1      equivalence (dtheta,dthta)
0043      1 c
0044      include 'common2.ini/list'
0045      1 c
0046      1 c      initialize common2
0047      1      data elist/60*0./,tlist/60*0./,
0048      1      $      dtheta/.01,.001/,lub/.05,.005/,deigen/.05,.005/,thtinc/.5/,
0049      1      $      ftol/1000./,maxitr/7/,alpha/3.14e-4/,h/50./,d/0./,prec/2./,
0050      1      $      wr0/2.5e5/,atnmax/50./,debug,typitr/0,0/,rpoly/1/,nrtlst/5/
0051      1 c
0052      c
0053      namelist/datum/freq,rho,azim,codip,magfld,sigma,epsr,beta,hprime,
0054      $      tlong,tlat,rlong,rlat,rbear,dmax,drmin,drmax,
0055      $      year,month,day,gmt,nprint,nprof,midpnt,igcd,ignd,mdir,
0056      $      lunit7,charge,mratio,coefnu,expnu,
0057      $      eigen,tlist,dtheta,lub,deigen,thtinc,ftol,maxitr,

```

# SW\$MAIN

```

0058      $      alpha,h,d,prec,wr0,atnmax,typitr,rpoly,nrtlst
0059      c
0060      complex theta
0061      character* 8 branch
0062      character*40 fname
0063      character*80 bcd
0064      c
0065      dimension coefnu(3),expnu(3),eigen(2,60)
0066      c
0067      c      Initialize MAIN
0068      data nuflag/0/,coefnu/1.816e11,2*4.540e09/,expnu/3*-.15/,
0069      $      eigen/120*0./,midpnt/0/
0070      c
0071      c      Unit:      Usage:
0072      c      2      input of alternate eigen list
0073      c      3      input of profiles along the path
0074      c      lunit7      output of mode parameters along the path
0075      c
0076      c
0077      10      read(5,1000,end=999) bcd
0078      print 1001,bcd
0079      branch=bcd(1:8)
0080      if(branch .eq. 'id'      ' .or. branch .eq. 'ID      ') go to 20
0081      if(branch .eq. 'name'    ' .or. branch .eq. 'NAME    ') go to 100
0082      if(branch .eq. 'eigen'   ' .or. branch .eq. 'EIGEN   ') go to 130
0083      if(branch .eq. 'profile' ' .or. branch .eq. 'PROFILE ') go to 200
0084      if(branch .eq. 'colfreq' ' .or. branch .eq. 'COLFREQ ') go to 250
0085      if(branch .eq. 'preseg'  ' .or. branch .eq. 'PRESEG  ') go to 400
0086      if(branch .eq. 'coord'   ' .or. branch .eq. 'COORD   ') go to 500
0087      if(branch .eq. 'quit'    ' .or. branch .eq. 'QUIT    ') go to 999
0088      c
0089      print *, 'ABORT MAIN: Control card not recognized '
0090      stop
0091      c
0092      c      Path identification
0093      20      read(5,1000) pathid
0094      print 1001,pathid
0095      go to 10
0096      c
0097      c      NAMELIST input
0098      100     read(5,datum)
0099      if(nprint .gt. 1) print datum
0100      if(freq .eq. 0.) then
0101      print *, 'ABORT MAIN: FREQ not input '
0102      stop
0103      end if
0104      if(magfld .gt. 1.e-02) magfld=magfld*1.e-04
0105      go to 10
0106      c
0107      c      Separate EIGEN list input
0108      130     read(bcd,1004) fname
0109      open(unit=2,file=fname,status='old')
0110      read(2,datum)
0111      close(unit=2)
0112      if(nprint .gt. 1) then
0113      do 131 m=1,60
0114      if(eigen(1,m) .eq. 0.) go to 132

```



# SWSMAIN

```

0115      131      km=m
0116      132      print 1040,d,h,(eigen(1,k),eigen(2,k),k=1,km)
0117      end if
0118      go to 10
0119      c
0120      c      Profile input
0121      200      read(bcd,1002) number
0122      nrspec=max0(1,number)
0123      nprof=0
0124      call profin(5,1,50,nprint,nrspec,lhtmx,htlist,lnlist)
0125      if(lhtmx .le. 0) then
0126          print *, 'ABORT MAIN: Ionospheric profile missing'
0127          stop
0128      end if
0129      go to 10
0130      c
0131      c      Collision frequency profile input
0132      250      nuflag=1
0133      call profin(5,2,50,nprint,nrspec,mhtmx,hcllist,cflist)
0134      if(mhtmx .le. 0) then
0135          print *, 'ABORT MAIN: Collision frequency profile missing'
0136          stop
0137      end if
0138      go to 10
0139      c
0140      c      Presegmented path
0141      400      npath=2
0142      go to 600
0143      c
0144      c      Automatic path segmentation
0145      500      npath=midpnt
0146      c
0147      c      Test all inputs before execution.
0148      c
0149      c      Count the modes
0150      600      do 602 m=1,60
0151          if(eigen(1,m) .eq. 0.) go to 603
0152      602      nmds=m
0153      603      if(nmds .le. 0) then
0154          print *, 'ABORT MAIN: No EIGEN list '
0155          stop
0156      end if
0157      c      Delete duplicate modes using DEIGEN
0158      if(nmds .gt. 1) then
0159          m=1
0160          l=2
0161      605      if(abs(eigen(1,m)-eigen(1,l)) .lt. deigen(1) .and.
0162          $      abs(eigen(2,m)-eigen(2,l)) .lt. deigen(2)) then
0163          c      Found a match so drop this mode.
0164          do 607 k=l,nmds
0165              eigen(1,k)=eigen(1,k+1)
0166      607      eigen(2,k)=eigen(2,k+1)
0167              eigen(1,nmds)=0.
0168              eigen(2,nmds)=0.
0169              nmds=nmds-1
0170              if(l .le. nmds) go to 605
0171      end if

```

SWSMAIN

```

0172         if(l .lt. nmds) then
0173             l=l+1
0174             go to 605
0175         end if
0176         if(m .lt. nmds) then
0177             m=m+1
0178             l=m+1
0179             go to 605
0180         end if
0181     end if
0182     c
0183     610 if(nmds .gt. 30) then
0184     c         Too many modes input, reduce the number by deleting input
0185     c         eigen list values which have attenuation rates in excess
0186     c         of atnmx and re-count the modes
0187             capk=1./(1.-.5*alpha*h)
0188             aconst=-182.0426*freq
0189             atnmx=atnmax
0190     611 nm=0
0191             do 614 m=1,nmds
0192                 if(eigen(1,m) .eq. 0.) go to 615
0193                 theta=cplx(eigen(1,m),eigen(2,m))*(.01745329252,0.)
0194                 if(aconst*aimag(capk*csin(theta)) .le. atnmx) then
0195                     if(nm .eq. 30) then
0196                         antmx=atnmx-5.
0197                         go to 611
0198                     else
0199                         nm=nm+1
0200                         elist(1,nm)=eigen(1,m)
0201                         elist(2,nm)=eigen(2,m)
0202                     end if
0203                 end if
0204     614 continue
0205     615 nmds=nm
0206             if(nprint .gt. 1)
0207                 $ print 1042,atnmax,(elist(1,k),elist(2,k),k=1,nmds)
0208             else
0209     c                 Keep all input modes.
0210                 do 616 m=1,nmds
0211                     elist(1,m)=eigen(1,m)
0212     616                 elist(2,m)=eigen(2,m)
0213                 end if
0214                 if(nmds .lt. 30) then
0215                     elist(1,nmds+1)=0.
0216                     elist(2,nmds+1)=0.
0217                 end if
0218     c
0219                 if(rpoly .eq. 1 .and. tlist(1,1) .eq. 0.) then
0220                     do 619 m=1,nmds
0221                         tlist(1,m)=elist(1,m)
0222     619                         tlist(2,m)=elist(2,m)
0223                     end if
0224     c
0225                 if(nuflag .eq. 0) then
0226                     mhtmx=2
0227                     hclist(1)=200.
0228                     hclist(2)=0.

```

SWSMAIN

```

0229      do 641 n=1,nrspec
0230      en=alog(coefnu(n))
0231      cflist(1,n)=en+expnu(n)*hcllist(1)
0232 641    cflist(2,n)=en+expnu(n)*hcllist(2)
0233      end if
0234      c
0235      if(nprof .eq. 1) then
0236      if(beta*hprime .eq. 0. .and. npath .ne. 2) then
0237      c      This is not a presegmented path, the profile specification
0238      c      must be made in the NAMELIST.
0239      print *, 'ABORT MAIN: BETA or HPRIME not input '
0240      stop
0241      end if
0242      nrspec=1
0243      lhtmx=2
0244      htlist(1)=200.
0245      htlist(2)=0.
0246      hprout=hprime
0247      else
0248      if(nprof .eq. 2) then
0249      c      Non-exponential profile, get a value for HPRIME
0250      call gethpr(wr0,hprout)
0251      end if
0252      end if
0253      c
0254      c      BEGIN:
0255      c
0256      call gcpath
0257      go to 10
0258      c
0259 999  stop
0260 1000 format(a)
0261 1001 format(1x,(a))
0262 1002 format(8x,i1)
0263 1004 format(8x,a)
0264 1040 format(' Input  EIGEN list:  D=',f5.2,' H=',f5.2/
0265 $      ' EIGEN =',6(f8.3,' ')/(8x,6(f8.3,' ')))
0266 1042 format(' Reduced EIGEN list:  ATNMAX=',f5.1/
0267 $      ' EIGEN =',6(f8.3,' ')/(8x,6(f8.3,' ')))
0268      end

```

```
0001      function cdang(arg)
0002      complex*16 arg
0003      real*8 cdang, argr, argi
0004      argr=dreal(arg)
0005      argi=dimag(arg)
0006      cdang=datan2(argi, argr)
0007      if(argi .ge. 0.d0) return
0008      cdang=cdang+6.2831853072d0
0009      return
0010      end
```

```

0001      subroutine comp f
0002      implicit real*8 (a-h,o-z)
0003      c
0004      include 'common2.for'
0018      include 'common3.for'
0043      c
0044      c=cdcos(theta*zdtr)
0045      csq=c*c
0046      s=cdsin(theta*zdtr)
0047      ssq=s*s
0048      call rbars
0049      if(rpoly .eq. 0) then
0050          call integ
0051      else
0052          call uspoly
0053      end if
0054      if(typitr-1) 5,10,15
0055      5      f=(rbar11*r11-zone)*(rbar22*r22-zone)
0056      $      -rbar11*rbar22*r12*r21
0057      return
0058      10      f=rbar11*r11-zone
0059      return
0060      15      f=rbar22*r22-zone
0061      return
0062      end

```

```

0001      subroutine drvequ
0002      implicit real *8 (a-h,o-z)
0003      c
0004      include 'common1.for'
0020      include 'common2.for'
0034      include 'common3.for'
0059      c
0060      complex*16 k2i,il,im,in,apd,usqd,yud,ysqd,u,usq,
0061      $          t11,t31,t42,t44,t12vrc,t14vrc,t32vrc,t34vrc,ct41,
0062      $          s11a,d11a,s11b,d11b,c12,c21,
0063      $          s12,d12,s21,d21,s22,d22,b11,b22,b12,b21
0064      real*8 lsq,msq,nsq,lm,ln,mn
0065      real*4 ht0
0066      dimension cx(3),capy(3),ysq(3)
0067      data dtr/1.745329252d-2/,coeffy/1.758796d11/,coeffx/3.182357d09/
0068      c
0069      entry intcmp
0070      k2i=dcmplx(0.d0,-0.5d0*wn)
0071      sindip=dsin(codip*dtr)
0072      drcosl=sindip*dcos(azim*dtr)
0073      drcosm=sindip*dsin(azim*dtr)
0074      drcosn=-dcos(codip*dtr)
0075      il=dcmplx(0.d0,drcosl)
0076      im=dcmplx(0.d0,drcosm)
0077      in=dcmplx(0.d0,drcosn)
0078      lsq=drcosl**2
0079      msq=drcosm**2
0080      nsq=drcosn**2
0081      lm=drcosl*drcosm
0082      ln=drcosl*drcosn
0083      mn=drcosm*drcosn
0084      c0=coeffx/omega**2
0085      cy=coeffy*magfld/omega
0086      do 1 k=1,nrspec
0087      cx(k)=c0*charge(k)**2/mratio(k)
0088      capy(k)=cy*charge(k)/mratio(k)
0089      1  ysq(k)=capy(k)**2
0090      call gethpr(100.*wr0,ht0)
0091      topht=ht0
0092      lhtmn=lht
0093      mhtmn=mht
0094      if(debug .le. 1) return
0095      print 110
0096      l=lhtmn
0097      m=mhtmn
0098      ht=topht
0099      10  slopel=(ht-htlist(l+1))/(htlist(l)-htlist(l+1))
0100      slopem=(ht-hclist(m+1))/(hclist(m)-hclist(m+1))
0101      ed=dexp(lnlist(l+1,1)+(lnlist(l,1)-lnlist(l+1,1))*slopel)
0102      en=dexp(cflist(m+1,1)+(cflist(m,1)-cflist(m+1,1))*slopem)
0103      capx=ed*cx(1)
0104      capz=en/omega
0105      wr=omega*capx/capz
0106      print 111,ht,ed,en,capx,capz,wr
0107      if(ht .lt. topht) return
0108      ht=d
0109      do 11 j=l,lhtmx

```

DRVEQU

```

0110      if(d .ge. htlist(j)) go to 12
0111      11      l=j
0112      12      do 13 j=m,mhtmx
0113      if(d .ge. hclist(j)) go to 10
0114      13      m=j
0115      c
0116      entry smtrix
0117      usqd=zero
0118      yud=zero
0119      ysqd=zero
0120      slopel=(ht-htlist(lht+1))/(htlist(lht)-htlist(lht+1))
0121      slopem=(ht-hclist(mht+1))/(hclist(mht)-hclist(mht+1))
0122      do 20 k=1,nrspec
0123      capx=dexp(lnlist(lht+1,k)
0124      $          +(lnlist(lht,k)-lnlist(lht+1,k))*slopel)*cx(k)
0125      capz=dexp(cflist(mht+1,k)
0126      $          +(cflist(mht,k)-cflist(mht+1,k))*slopem)/omega
0127      u=dcmplx(1.d0,-capz)
0128      usq=u*u
0129      capd=-capx/(u*(usq-ysq(k)))
0130      if(cdabs(capd) .gt. 1.d-30) then
0131      usqd=usqd+usq*capd
0132      yud=yud+capy(k)*u*capd
0133      ysqd=ysqd+ysq(k)*capd
0134      end if
0135      20      continue
0136      crvtrm=alpha*(h-ht)
0137      m11=usqd-lsq*ysqd-crvtrm
0138      m22=usqd-msq*ysqd-crvtrm
0139      m33=usqd-nsq*ysqd-crvtrm
0140      m12=-in*yud-lm*ysqd
0141      m21= in*yud-lm*ysqd
0142      m13= im*yud-ln*ysqd
0143      m31=-im*yud-ln*ysqd
0144      m23=-il*yud-mn*ysqd
0145      m32= il*yud-mn*ysqd
0146      capd=zone/(zone+m33)
0147      t11=-s*m31*capd
0148      t12vrc=s*m32*capd/c
0149      t14vrc=(csq+m33)*capd/c
0150      t31=m23*m31*capd-m21
0151      t32vrc=c+(m22-m23*m32*capd)/c
0152      t34vrc=s*m23*capd/c
0153      ct41=(zone+m11-m13*m31*capd)*c
0154      t42=m32*m13*capd-m12
0155      t44=-s*m13*capd
0156      s11a=t11+t44
0157      d11a=t11-t44
0158      s11b=t14vrc+ct41
0159      d11b=t14vrc-ct41
0160      s12=t12vrc+t42
0161      d12=t12vrc-t42
0162      s21=t34vrc+t31
0163      d21=t34vrc-t31
0164      s22=c+t32vrc
0165      d22=c-t32vrc
0166      c

```

# DRVEQU

```

0167      if(ht .eq. topht) call intalr
0168      c
0169      entry rderiv
0170      k=0
0171      do 30 j=1,7,2
0172      k=k+1
0173      if(dabs(logr(j)) .gt. 15.d0)
0174      $   logrs(k)=dcmplx(dsign(15.d0,logr(j)),0.d0)
0175      30  rs(k)=cdexp(logrs(k))
0176      b11=r11*(d11a-d11b)
0177      b22=r22*d22
0178      b12=r12*d21
0179      b21=r21*s12
0180      c12=r12*s21
0181      c21=r21*d12
0182      d11dh=k2i*
0183      $   (b11+b12+b21-s11b-s11b+(r12*r21*d22+c12+c21-d11a-d11b)/r11)
0184      d122dh=k2i*
0185      $   (b12+b21+b22-s22-s22+(r12*r21*(d11a-d11b)+b12+b21+d22)/r22)
0186      d112dh=k2i*
0187      $   (b11+b12+b22+s11a-s11b-s22+(r11*s12+d12)*(r22+zone)/r12)
0188      d121dh=k2i*
0189      $   (b11+b21+b22-s11a-s11b-s22+(r11*d21+s21)*(r22+zone)/r21)
0190      c
0191      if(debug .gt. 2) then
0192      print 100,ht,delh,logr,d1rdh
0193      end if
0194      return
0195      c
0196      100 format(f9.4,1pe12.4,4(1x,2e12.3)/21x,4(1x,2e12.3))
0197      110 format(/' Electron density parameters: ht den nu',
0198      $      8x,'x z w')
0199      111 format(27x,f7.1,1p5e10.2)
0200      end

```



```

0001      subroutine extrap
0002      c
0003      c      This routine sets up and maintains the data sets for the quadratic
0004      c      extrapolation of eigen's down the propagation path.
0005      c
0006      include 'common1.for'
0022      include 'common2.for'
0036      c
0037      logical brwstr
0038      complex*8 t(30),y(30),ys(3,30),s,tb,stb,capk,coeff,ngsq,
0039      $          zero/(0.,0.)/,zone/(1.,0.)/,zmplxi/(0.,1.)/
0040      dimension xs(3)
0041      equivalence (elist,y),(tlist,t)
0042      data dtr/.01745329252/
0043      c
0044      if(lx .eq. 0) then
0045      c      This is the first point on the propagation path.
0046      c      Set up constants and remove input modes with attenuation
0047      c      rates greater than atnmax.
0048      capk=cplx(1.-.5*alpha*h,0.)
0049      coeff=cplx(0.,182.0428*freq)/capk
0050      c
0051      c      Get Brewster mode
0052      if(sigma .lt. 1.e-3) then
0053      ngsq=cplx(epsr,-1.7975e7*sigma/freq)
0054      stb=csqrt(ngsq/(ngsq+zone))*capk
0055      atten=coeff*stb
0056      if(atten .le. atnmax) then
0057      c      The Brewster mode is contained within the normal set.
0058      tb=(90.,0.)
0059      brwstr=.false.
0060      else
0061      c      The Brewster mode is outside the normal set.
0062      if(atten .le. 2.*atnmax) then
0063      c      The attenuation rate is not excessive.
0064      tb=cplx(0.,-1./dtr)*clog(csqrt(zone-stb**2)+zmplxi*stb)
0065      brwstr=.true.
0066      else
0067      c      The attenuation rate is excessive.
0068      tb=(90.,0.)
0069      brwstr=.false.
0070      end if
0071      end if
0072      else
0073      tb=(90.,0.)
0074      brwstr=.false.
0075      end if
0076      do 139 k=1,30
0077      mode(k)=k
0078      137 if(real(y(k)) .gt. 0.) then
0079      if(brwstr) then
0080      c      If this mode is near the Brewster, then keep it.
0081      if(abs(real(y(k)-tb)) .le. 1. .and.
0082      $      abs(aimag(y(k)-tb)) .le. .5) go to 139
0083      end if
0084      atten=coeff*csin(y(k)*dtr)
0085      if(atten .gt. atnmax) then

```

# EXTRAP

```

0086          do 138 l=k,30
0087            t(l)=t(l+1)
0088 138        y(l)=y(l+1)
0089            t(30)=zero
0090            y(30)=zero
0091            go to 137
0092          end if
0093        end if
0094 139        continue
0095        return
0096      end if
0097    c
0098      x=rho
0099      if(nprint .gt. 1) print 1000,x
0100      nmds=ls
0101      do 143 k=1,nmds
0102        s=zero
0103        do 142 l1=1,lx
0104          p=1.
0105          do 141 l2=1,lx
0106            if(l1 .eq. l2) go to 141
0107            p=p*(x-xs(l2))/(xs(l1)-xs(l2))
0108 141          continue
0109 142          s=s+p*ys(l1,k)
0110            if(nprint .gt. 1) print 1001,mode(k),s
0111            t(k)=s
0112 143          y(k)=s
0113        c
0114        c      Scan the extrapolated eigen's for invalid values.
0115          do 151 k=1,nmds
0116            if(real(y(k)) .le. 0. .or. real(y(k)) .ge. 90. .or.
0117 $          aimag(y(k)) .ge. 0.) then
0118              print *, 'ERROR EXTRAP: Extrapolated mode',mode(k)
0119              lost=1
0120              return
0121            end if
0122 151          continue
0123            if(nmds .lt. 30) then
0124              t(nmds+1)=zero
0125              y(nmds+1)=zero
0126            end if
0127          return
0128        c
0129        entry xsave
0130      c
0131      c      This entry point is called after execution of WVGUID.
0132      c      It updates the data sets used to do the quadratic extrapolation.
0133      c
0134      x=rho
0135      if(lx .lt. 3) then
0136        lx=lx+1
0137      else
0138        do 21 l=1,2
0139          xs(l)=xs(l+1)
0140          do 21 k=1,nmds
0141 21          ys(l,k)=ys(l+1,k)
0142        end if

```

# EXTRAP

```

0143      ls=nmds
0144      xs(lx)=x
0145      do 25 k=1,nmds
0146 25     ys(lx,k)=y(k)
0147      c
0148      c      Keep all eigen's at first input distance.
0149      if(lx .eq. 1) then
0150          modes=nmds
0151          return
0152      end if
0153      c      j is counter for modes to be output by SAVEMC
0154      c      k is counter for modes to be used by WVGUID
0155      j=0
0156      k=1
0157 251     if(k .gt. nmds) return
0158         j=j+1
0159         if(brwstr) then
0160             c      Check if this mode is near the Brewster; if so, then keep it.
0161             if(abs( real(y(k)-tb)) .le. 1. .and.
0162 $         abs(aimag(y(k)-tb)) .le. .5) go to 256
0163         end if
0164         atten=coeff*csin(y(k)*dtr)
0165         if(atten .gt. atnmax) then
0166             c      Delete k-th mode
0167             do 253 l=1,4
0168 253         T term(l,j)=zero
0169             nmds=nmds-1
0170             ls=nmds
0171             if(nmds .eq. 0) then
0172                 print *, 'ERROR EXTRAP: All modes have been deleted'
0173                 lost=1
0174                 t(1)=zero
0175                 y(1)=zero
0176                 return
0177             end if
0178             if(k .gt. nmds) then
0179 257         modes=modes-1
0180                 if(real(T term(1,modes)) .ne. 0.) return
0181                 go to 257
0182             else
0183                 do 254 l=k,nmds
0184                     mode(l)=mode(l+1)
0185                     t(l)=t(l+1)
0186                     y(l)=y(l+1)
0187                     do 254 m=1,lx
0188                         ys(m,l)=ys(m,l+1)
0189 254         continue
0190                     t(nmds+1)=zero
0191                     y(nmds+1)=zero
0192                     go to 251
0193                 end if
0194             end if
0195 256         k=k+1
0196         go to 251
0197      c
0198 1000     format(/' Extrapolated EIGEN list for x =',f8.3)
0199 1001     format(i5,5x,2f8.3,f12.3)
0200     end

```

```

0001      subroutine gcdbr(dl,clt1,clt2,rho,br,inb)
0002      c
0003      c      Returns great circle distance and geographic bearing angle
0004      c
0005      c      Input: DL is longitude of point 2 minus longitude of point 1
0006      c                  CLT1 is co-latitude of point 1
0007      c                  CLT2 is co-latitude of point 2
0008      c                  INB=0: RHO is computed and
0009      c                        BR from point 1 thru point 2 is computed at 1
0010      c                  INB=1: RHO is input and
0011      c                        BR from point 1 thru point 2 is computed at 2
0012      c
0013      c      Output: RHO is great circle distance between the input points
0014      c                  BR is geographic bearing angle measured clockwise from
0015      c                        due North
0016      c
0017      c      All coordinates, RHO and BR are in radians
0018      c      Sign convention is + for West and North
0019      c
0020      data pi/3.14159265e0/,twopi/6.28318531e0/
0021      c
0022      reduce(arg)=sign(amin1(abs(arg),1.),arg)
0023      c
0024      cclt1=cos(clt1)
0025      sclt1=sin(clt1)
0026      cclt2=cos(clt2)
0027      sclt2=sin(clt2)
0028      c
0029      adl=abs(dl)
0030      if(adl .ge. pi) then
0031          dl=amod(dl,twopi)
0032      else
0033          adl=abs(dl)
0034      end if
0035      if(inb .eq. 1) then
0036          if(rho .gt. pi) then
0037              gcd=twopi-rho
0038          else
0039              gcd=rho
0040          end if
0041      end if
0042      if(abs(clt1) .le. 1.e-6 .or. abs(clt1-pi) .le. 1.e-6) go to 10
0043      if(adl .le. 1.e-6) go to 20
0044      if(abs(adl-pi) .le. 1.e-6) go to 30
0045      if(adl .ge. pi) then
0046          if(dl .ge. 0.) then
0047              dl=dl-twopi
0048          else
0049              dl=dl+twopi
0050          end if
0051      end if
0052      if(inb .eq. 0) then
0053          cgcd=cclt1*cclt2+sclt1*sclt2*cos(dl)
0054          gcd=acos(reduce(cgcd))
0055          if(abs(cgcd-1.) .le. 1.e-6) then
0056              br=0.
0057          else

```

GCDBR

```

0058         br=acos(reduce((cclt2-cclt1*cgcd)/(sclt1*sin(gcd))))
0059     end if
0060 else
0061     if(abs(gcd) .le. 1.e-6) then
0062         br=0.
0063     else
0064         br=pi-acos(reduce((cclt1-cclt2*cos(gcd))/(sclt2*sin(gcd))))
0065     end if
0066 end if
0067 if(dl .lt. 0.) br=twopi-br
0068 go to 40
0069 c
0070 c     point 1 is at one of the poles
0071 10 if(inb .eq. 0) gcd=abs(clt1-clt2)
0072 if(abs(clt1) .le. 1.e-6) then
0073     br=pi-dl
0074 else
0075     br=dl
0076 end if
0077 go to 40
0078 c
0079 c     coordinates are on same longitude
0080 20 dc=clt1-clt2
0081 if(dc .ge. 0.) then
0082     br=0.
0083 else
0084     dc=-dc
0085     br=pi
0086 end if
0087 if(inb .eq. 0) gcd=dc
0088 go to 40
0089 c
0090 c     coordinates are on opposite longitudes
0091 30 dc=clt1+clt2
0092 if(dc .le. pi) then
0093     if(inb .eq. 0) then
0094         br=0.
0095     else
0096         br=pi
0097     end if
0098 else
0099     dc=twopi-dc
0100     if(inb .eq. 0) then
0101         br=pi
0102     else
0103         br=0.
0104     end if
0105 end if
0106 if(inb .eq. 0) gcd=dc
0107 c
0108 c     long path calculations
0109 40 if(inb .eq. 1) then
0110     if(rho .gt. pi) then
0111         if(br .lt. pi) then
0112             br=br+pi
0113         else
0114             br=br-pi

```

GCDBR

```
0115         end if
0116     end if
0117 end if
0118 c
0119 90     if(inb .eq. 0) rho=gcd
0120     return
0121 end
```

```

0001      subroutine gcpath
0002      c
0003      c      sign convention: + for west and north, - for east and south
0004      c
0005      include 'common1.for'
0021      include 'common2.for'
0035      c
0036      dimension prof1(50,3),prof2(50,3)
0037      real lng,long,lat,m1,m2,mgf
0038      character*72 bcd,preseg
0039      logical first
0040      data dtr/1.745329e-2/,re/6.366/,alt/80./
0041      c
0042      c      min=0 --- normal
0043      c      =1 --- interpolating between preseg values
0044      c      =2 --- last interpolation interval
0045      c
0046      c      lost=0 -- no trouble with modes
0047      c      =1 -- dropped a mode in WVGUID or EXTRAP
0048      c      =2 -- all modes found but one or more changed significantly
0049      c      from the extrapolated values
0050      c
0051      c      nprof=0 - use profile from MAIN
0052      c      1 - use exponential profile
0053      c      2 - read non-exponential profiles along path
0054      c      WARNING: the heights must match in each profile
0055      c
0056      first=.true.
0057      write(90,*) 'Failure at RHO 1'
0058      c
0059      lx=0
0060      min=0
0061      bta=0.
0062      sig=0.
0063      mgf=0.
0064      signal=0.
0065      tlng=tlong*dtr
0066      tc1t=(90.-tlat)*dtr
0067      rho0=rho
0068      rhop=rho
0069      drho=drmin
0070      if(rbear .eq. 720.) then
0071          call gcdbr((tlong-rlong)*dtr,tc1t,(90.-rlat)*dtr,gcd,xtr,0)
0072          brng=xtr/dtr
0073          if(igcd .eq. 1) then
0074              rhomax=gcd*re
0075          else
0076              rhomax=dmax
0077          end if
0078      else
0079          xtr=rbear*dtr
0080          brng=rbear
0081          rhomax=dmax
0082      end if
0083      c
0084      20      if(npath .eq. 2) then
0085      c          Presegmented path

```

# GCPATH

```

0086      read(5,2000,end=900) preseg
0087      read(preseg,*) rho,azm,cdp,mgf,sig,eps,bta,hprm
0088      if(rho .eq. 40.) then
0089          print *, 'End of preseg data'
0090          rewind 90
0091          write(90,2003)
0092          go to 999
0093      else if(rho .gt. rhomax) then
0094          print *, 'DMAX reached before end of preseg data '
0095          rewind 90
0096          write(90,2003)
0097          go to 900
0098      end if
0099      if(first) then
0100          rho0=rho
0101          rhop=rho
0102      end if
0103      drho=rho-rhop
0104      if(drho .lt. 0.) then
0105          print *, 'ABORT GCPATH: Preseg rhos out of order'
0106          go to 900
0107      end if
0108      if(nprof .eq. 2) then
0109          read(3,2000) bcd
0110          if(bcd(1:8) .ne. 'profile ' .and.
0111             bcd(1:8) .ne. 'PROFILE ') then
0112              print *, 'ABORT GCPATH: PROFILE control string missing'
0113              go to 900
0114          end if
0115          read(bcd,2001) nn
0116          if(nrspec .ne. max0(1,nn)) then
0117              print *, 'ABORT GCPATH: Number of species is incorrect'
0118              go to 900
0119          end if
0120          call profin(3,1,50,nprint,nrspec,lhtmx,htlist,lnlist)
0121          if(lhtmx .lt. 0) then
0122              print *, 'ABORT GCPATH: Profile missing'
0123              go to 900
0124          end if
0125          if(lhtmx .gt. 0) then
0126              if(lhtmx .ne. lhtmx1) then
0127                  print *, 'ABORT GCPATH: Number of heights is incorrect'
0128                  go to 900
0129              end if
0130              call gethpr(wr0,hprout)
0131          end if
0132      else
0133          if(nprof .eq. 1) then
0134              if(bta .gt. 0.) then
0135                  beta=bta
0136                  hprime=hprm
0137              end if
0138              if(beta*hprime .eq. 0.) then
0139                  print *, 'ABORT GCPATH: BETA or HPRIME not input'
0140                  go to 900
0141              end if
0142          end if

```



## GCPATH

```

0143      c      Calculate exponential profile:
0144      lnlist(1,1)=cflist(1,1)+beta*(htlist(1)-hprime)-9.4517306
0145      lnlist(2,1)=cflist(2,1)+beta*(htlist(2)-hprime)-9.4517306
0146      hprout=hprime
0147      end if
0148  end if
0149      c
0150      if(npath .eq. 1) then
0151      c      Calculate midpoint distance:
0152      rho=.5*rhomax
0153      else
0154      if(rho .eq. 0.) then
0155      c      Begin at xmtr
0156      lng=tlng
0157      clt=tcclt
0158      br=xtr
0159      end if
0160      end if
0161      c
0162  30      if(rho .gt. 0.) then
0163      gcd=rho/re
0164      call recvr(tlng,tclt,xtr,gcd,lng,clt)
0165      if(rho .eq. 20.) then
0166      c      At the antipode of the transmitter.
0167      br=9.4247779608-xtr
0168      if(br .gt. 6.2831853072) br=br-6.2831853072
0169      else
0170      call gcdbr(tlng-lng,tclt,clt,gcd,br,1)
0171      end if
0172      end if
0173      bpath=br/dtr
0174      long=lng/dtr
0175      colat=clt/dtr
0176      lat=90.-colat
0177      c
0178      if(sig .gt. 0.) then
0179      sigma=sig
0180      epsr=eps
0181      else
0182      if(ignd .eq. 1) call ground(long,lat,ncode,sigma,epsr)
0183      end if
0184      c      If conductivity has changed, then restart extrapolation
0185      if(signal .ne. sigma .and. signal .ne. 0.) then
0186      min=0
0187      lx=0
0188      call xsave
0189      lx=0
0190      end if
0191      c
0192      if(mgf .gt. 0.) then
0193      azim=azm
0194      codip=cdp
0195      magfld=mgf
0196      if(magfld .gt. 1.e-02) magfld=magfld*1.e-04
0197      else
0198      call newmag(0,alt,lng,clt,bmf,dip,b,br,bp,bt)
0199      azim=bpath-bmf/dtr

```

## GCPATH

```

0200      if(azim .lt. 0.) then
0201          azim=azim+360.
0202      else if(azim .gt. 360.) then
0203          azim=azim-360.
0204      end if
0205      codip=90.-dip/dtr
0206      magfld=b*1.0e-04
0207  c
0208      if(mdir .eq. 1) then
0209  c          Reverse azim if contours for xmtr deployment
0210          azim=azim-180.
0211          if(azim .lt. 0.) then
0212              azim=azim+360.
0213          else if(azim .gt. 360.) then
0214              azim=azim-360.
0215          end if
0216      end if
0217  c
0218      end if
0219      print 1000,rho,long,lat,bpath,azim,codip,magfld,sigma,epsr
0220  c
0221  40      lost=0
0222          x=rho
0223          call extrap
0224          if(lost .eq. 1) go to 100
0225          call wvguid
0226          if(nmds .eq. 0 .and. (rho .eq. 0. .or. npath .eq. 1 )) then
0227              print *, 'ABORT GCPATH: Failure at starting rho'
0228              go to 900
0229          end if
0230          if(lost .eq. 1) go to 100
0231          call xsave
0232          if(lost .eq. 1) go to 100
0233          rhop=rho
0234          if(min .eq. 1) go to 50
0235          if(first) then
0236  c              Primary output file:
0237                  open(unit=lunit7,status='new')
0238                  if(year .eq. 0 .and. month .eq. 0 .and. day .eq. 0) then
0239                      write(lunit7,1030) tlong,tlat,brng,beta,hprime,pathid
0240                  else
0241                      write(lunit7,1031) tlong,tlat,brng,beta,hprime,
0242  $                      mod(year,100),month,day,gmt,pathid
0243                  end if
0244                  first=.false.
0245          end if
0246          call savemc
0247          if(npath .eq. 1) then
0248              rewind 90
0249              write(90,2003)
0250              go to 999
0251          else
0252              rewind 90
0253              write(90,2002) rho
0254          end if
0255          if(rho+.002 .ge. rhomax) go to 900
0256  c

```

## GCPATH

```

0257      rho1=rho
0258      al=azim
0259      cl=codip
0260      ml=magfld
0261      el=epsr
0262      sl=alog(sigma)
0263      sigmal=sigma
0264      if(nprof .gt. 0) then
0265          lhtmx1=lhtmx
0266          do 48 l=1,lhtmx
0267              do 48 m=1,nrspec
0268                  48      prof1(l,m)=lnlist(l,m)
0269              end if
0270          if(min .eq. 2) then
0271              min=0
0272              go to 70
0273          end if
0274      c
0275      50      if(lost .eq. 2) then
0276          if(min .eq. 0) then
0277              drho=amax1(drho-drmin,drmin)
0278          else
0279              drho=.5*(rho2-rho)
0280          end if
0281      else
0282          if(min .eq. 0) then
0283              drho=amin1(drho+drmin,drmax)
0284          else
0285              drho=rho2-rho
0286          end if
0287      end if
0288      c
0289      70      if(min .eq. 0 .and. npath .eq. 2) go to 20
0290      rho=rho+drho
0291      if(rho+.002 .gt. rhomax) then
0292          drho=drho-rho+rhomax
0293          rho=rhomax
0294      end if
0295      if(min .eq. 1) go to 120
0296      go to 30
0297      c
0298      c      Back up on propagation path
0299      100      if(rho .eq. rho0) then
0300          print *, 'ABORT GCPATH: Failure at starting rho'
0301          go to 900
0302      end if
0303      if(min-1) 101,102,103
0304      101      if(npath .eq. 2) go to 105
0305              if(drho .le. drmin) go to 110
0306              nrd=.5*drho/drmin
0307              if(nrd .eq. 0) go to 110
0308              drho=nrd*drmin
0309              rho=rho1+drho
0310              go to 30
0311      103      min=1
0312              drho=drhop
0313      102      drho=.5*drho

```

## GCPATH

```

0314      if(drho .lt. .015125) then
0315          print *, 'ABORT GCPATH: Backup interval is less than 0.015125'
0316          go to 900
0317      end if
0318  104    rho=rhop+drho
0319          go to 120
0320      c
0321  105    if((rho-rho1)/drmin .gt. 10.) then
0322          print *, 'ABORT GCPATH: Preseg interval too large for efficient
0323      $processing'
0324          go to 900
0325      end if
0326      c
0327      c      Begin interpolation
0328  110    min=1
0329          drho=.5*(rho-rho1)
0330          if(drho .lt. .015125) then
0331              print *, 'ABORT GCPATH: Backup interval is less than 0.015125'
0332              go to 900
0333          end if
0334          rho2=rho
0335          a2=azim
0336          if(a2-a1 .gt. 180.) then
0337              a2=a2-360.
0338          else if(a2-a1 .lt. -180.) then
0339              a2=a2+360.
0340          end if
0341          c2=codip
0342          m2=magfld
0343          e2=epsr
0344          s2=alog(sigma)
0345          sigma2=sigma
0346          if(nprof .gt. 0) then
0347              lhtmx2=lhtmx
0348              do 111 l=1,lhtmx
0349                  do 111 m=1,nrspec
0350  111      prof2(l,m)=lnlist(l,m)
0351              end if
0352          rho=rho1+drho
0353      c
0354  120    if(rho+.002 .ge. rho2) then
0355      c      End of interpolation
0356          min=2
0357          drhop=drho
0358          drho=drmin
0359          rho=rho2
0360          azim=a2
0361          if(azim .lt. 0.) then
0362              azim=azim+360.
0363          else if(azim .gt. 360.) then
0364              azim=azim-360.
0365          end if
0366          codip=c2
0367          magfld=m2
0368          epsr=e2
0369          sigma=sigma2
0370          if(nprof .gt. 0) then

```

## GCPATH

```

0371          do 121 l=1,lhtmx
0372          do 121 m=1,nrspec
0373      121      lnlist(l,m)=prof2(l,m)
0374          end if
0375      else
0376      c          Interpolate
0377          slope=(rho-rho1)/(rho2-rho1)
0378          azim=a1+slope*(a2-a1)
0379          if(azim .lt. 0.) then
0380              azim=azim+360.
0381          else if(azim .gt. 360.) then
0382              azim=azim-360.
0383          end if
0384          codip=c1+slope*(c2-c1)
0385          magfld=m1+slope*(m2-m1)
0386          epsr=e1+slope*(e2-e1)
0387          sigma=exp(s1+slope*(s2-s1))
0388          if(nprof .gt. 0) then
0389              do 122 l=1,lhtmx
0390              do 122 m=1,nrspec
0391      122          lnlist(l,m)=prof1(l,m)+slope*(prof2(l,m)-prof1(l,m))
0392              end if
0393          end if
0394          print 1002, rho,azim,codip,magfld,sigma,epsr
0395          go to 40
0396      c
0397      900      if(npath .eq. 2) then
0398      903          read(5,2000,end=999) bcd
0399              if(bcd(1:5) .eq. '40,0,') go to 999
0400              go to 903
0401          end if
0402      999      write(lunit7,1032)
0403              close(unit=lunit7)
0404              print *, 'Execution terminating for this path'
0405              return
0406      c
0407      1000      format(/' Propagation path parameters: rho long lat',
0408          $          4x,'bear azim codip magfld sigma epsr'/
0409          $          26x,f10.3,f10.2,4f9.2,e11.2,1pe11.2,0pf8.2)
0410      1002      format(/11x,' Interpolated path parameters: rho azim',
0411          $          5x,'codip magfld sigma epsr'/
0412          $          38x,f10.3,f10.2,f9.2,e11.2,1pe11.2,0pf8.2)
0413      1030      format('sw xmtr',f7.1,2f6.1,' prof',f5.2,f5.1/a80)
0414      1031      format('sw xmtr',f7.1,2f6.1,' prof',f5.2,f5.1,
0415          $          ' ',3(i2.2,'/'),f4.1,')'/a80)
0416      1032      format('r 40.')
0417      2000      format(a72)
0418      2001      format(8x,i1)
0419      2002      format(f6.3)
0420      2003      format('40')
0421      end

```

```

0001      subroutine gethpr(wr,hpr)
0002      c
0003      c      Routine to determine the height where omega sub r is a
0004      c      specific value. The value returned is to nearest km.
0005      c
0006      include 'common1.for'
0022      c
0023      data coeffx/3.182357e9/
0024      c
0025      c      Start at the bottom of the profile and work up.
0026      c
0027      lht=lhtmx-1
0028      mht=mhtmx-1
0029      ht=amin1(htlist(lhtmx),hclist(mhtmx))
0030      10      if(lht .gt. 1 .and. ht .ge. htlist(lht-1)) then
0031          lht=lht-1
0032          go to 10
0033      end if
0034      12      if(mht .gt. 1 .and. ht .ge. hclist(mht-1)) then
0035          mht=mht-1
0036          go to 12
0037      end if
0038      slope l=(ht-hclist(lht+1))/(htlist(lht)-htlist(lht+1))
0039      slope m=(ht-hclist(mht+1))/(hclist(mht)-hclist(mht+1))
0040      sum=0.
0041      do 14 n=1,nrspec
0042          dn=exp(lnlist(lht+1,n)+(lnlist(lht,n)-lnlist(lht+1,n))*slope l)
0043          cf=exp(cflist(mht+1,n)+(cflist(mht,n)-cflist(mht+1,n))*slope m)
0044      14      sum=sum+coeffx*dn/(mratio(n)*cf)
0045      if(sum .gt. wr) then
0046          hpr=ht
0047          if(nprint .gt. 1) then
0048              print *
0049              print *, 'GETHPR:  wr, hpr=',wr,hpr
0050          end if
0051          return
0052      end if
0053      ht=ht+1.
0054      go to 10
0055      end

```

```

0001      subroutine ground(xlong,xlat,ncode,sigma,epsr)
0002      c
0003      c      Returns conductivity code, conductivity, dielectric constant
0004      c
0005      c      Input:  XLONG is West longitude in degrees
0006      c                (i.e., -117.3 for 117 degrees, 18 minutes East)
0007      c                XLAT is North latitude  in degrees
0008      c                (i.e., 32.8 for 32 degrees, 48 minutes North)
0009      c
0010      c      Output: NCODE is conductivity code from GRNDMAP.DAT
0011      c                (ncode=0 is sea water, =1 is ice; see DATA below)
0012      c                SIGMA is mho/m
0013      c                EPSR is the dielectric constant
0014      c                A list of sigma and epsr is also placed into a common.
0015      c
0016      c      Requires:  GRNDMAP.DAT
0017      c
0018      c      include '[305021.jaflib]data files.for/list'
0019      1      character*40 grnd$d/'user$disk$3:[305021.jaflib]grndmap.dat'/
0020      1      character*40 itsn$d/'user$disk$3:[305021.jaflib]itsnoise.dat'/
0021      1      character*40 wrld$d/'user$disk$3:[305021.jaflib]world.dat'/
0022      c
0023      common/grnd$/sss(10),rrr(10)
0024      logical first/.true./
0025      dimension lcode(361),map(4530),ss(10),rr(10)
0026      data ss/1.e-5,3.e-5,1.e-4,3.e-4,1.e-3,3.e-3,1.e-2,3.e-2,.1,4./
0027      data rr/5.,5.,10.,15.,15.,15.,15.,80.,81./
0028      if(first) then
0029          open(unit=8,file=grnd$d,status='old',readonly)
0030          read(8,1) lcode,map
0031      1      format(9i8)
0032          close(unit=8)
0033          do 2 l=1,10
0034              sss(l)=ss(l)
0035      2      rrr(l)=rr(l)
0036          first=.false.
0037      end if
0038      phi=xlong
0039      if(phi .gt. 180.) then
0040          phi=phi-360.
0041      else
0042          if(phi .lt. -180.) phi=phi+360.
0043      end if
0044      if(abs(phi) .gt. 180. .or. abs(xlat) .gt. 90.01) then
0045          print 11,xlong,xlat
0046      11      format(/' ***** Error in GROUND:  Xlong      Xlat'
0047      $          /26x,2f9.2)
0048          stop
0049      end if
0050      lat=181.-2.*xlat
0051      if(lat .gt. 360) lat=360
0052      long=361.-2.*phi
0053      if(long .gt. 720) long=1
0054      l1=lcode(lat)
0055      l2=lcode(lat+1)-1
0056      do 21 l=l1,l2
0057          map(l)=map(l)/10000

```

## GROUND

```

0058      mapl=map(l)-10000*maplm1
0059      mlong=mapl/10
0060      if(mlong.ge. long) go to 31
0061  21      continue
0062  31      ncd=mapl-mlong*10
0063      mlong=maplm1/10
0064      if(mlong.lt. long) go to 41
0065      ncd=maplm1-mlong*10
0066  41      if(ncd.lt. 0.or. ncd.gt. 9) then
0067          print 51,xlong,xlat,long,lat,l1,l2,mlong,ncode
0068  51      format(/' ***** Error in GROUND: Xlong      Xlat',
0069          $          ' long lat l1 l2 mlong ncode'
0070          $          /26x,2f9.2,4i6,2i8)
0071          stop
0072      end if
0073      ncode=ncd
0074      if(ncode.eq. 0) ncode=10
0075      sigma=ss(ncode)
0076      epsr= rr(ncode)
0077      return
0078      end

```



```

0001      subroutine intalr
0002      implicit real *8 (a-h,o-z)
0003      c
0004      include 'common2.for'
0018      include 'common3.for'
0043      c
0044      complex*16 q,p,t,d11,d13,d31,d33,delta,fnsq,froot,
0045      $      com1,com3,csqm22,csqm33,b3,b2,b1,b0
0046      dimension phase1(8), phase2(8), p(2), t(2), q(4)
0047      equivalence (logr11,phase1(1))
0048      data pi/3.141592653d0/,twopi/6.283185307d0/
0049      c
0050      if(isotrp-1) 10,100,102
0051      10      com1=zone+m11
0052      com3=zone+m33
0053      csqm22=csq+m22
0054      csqm33=csq+m33
0055      b3=0.25d0*s*(m13+m31)/com3
0056      b2=(-csqm33*com1+m13*m31-com3*csqm22+m23*m32)/(6.d0*com3)
0057      b1=s*(m12*m23+m32*m21-csqm22*(m13+m31))/(4.d0*com3)
0058      b0=(com1*csqm22*csqm33+m12*m23*m31+m32*m21*m13-m13*m31*csqm22
0059      $      -com1*m23*m32-m12*m21*csqm33)/com3
0060      call qartic(q,b3,b2,b1,b0,debug,newq)
0061      c
0062      do 30 n=1,2
0063      d11=zone+m11-q(n)**2
0064      d13=m13+s*q(n)
0065      d31=m31+s*q(n)
0066      d33=zone+m33-s**2
0067      delta=d11*d33-d13*d31
0068      p(n)=(-m12*d33+d13*m32)/delta
0069      t(n)=q(n)*p(n)-s*(-d11*m32+m12*d31)/delta
0070      pyntng=t(n)*dconjg(p(n))+q(n)
0071      if(pyntng .lt. 0.) print 201,theta,q(n),pyntng
0072      30      continue
0073      delta=(t(1)*c+p(1))*(c+q(2))-(t(2)*c+p(2))*(c+q(1))
0074      r11=((t(1)*c-p(1))*(c+q(2))-(t(2)*c-p(2))*(c+q(1)))/delta
0075      r22=((t(1)*c+p(1))*(c-q(2))-(t(2)*c+p(2))*(c-q(1)))/delta
0076      r12=-2.d0*c*(t(1)*p(2)-t(2)*p(1))/delta
0077      r21=-2.d0*c*(q(1)-q(2))/delta
0078      40      logr11=cdlog(r11)
0079      logr12=cdlog(r12)
0080      logr21=cdlog(r21)
0081      logr22=cdlog(r22)
0082      if(adjflg .eq. 1) then
0083      do 70 n=2,8,2
0084      50      if(phase1(n)-phase2(n) .le. pi) go to 60
0085      phase1(n)=phase1(n)-twopi
0086      go to 50
0087      60      if(phase2(n)-phase1(n) .le. pi) go to 70
0088      phase1(n)=phase1(n)+twopi
0089      go to 60
0090      70      continue
0091      end if
0092      do 90 n=2,8,2
0093      90      phase2(n)=phase1(n)
0094      if(debug .gt. 2) print 202

```

# INTALR

```

0095      return
0096      c
0097      100  ir=1
0098           fnsq=zone+m11
0099           froot=cdsqrt(csq+m11)
0100           go to 106
0101      101  r11=(fnsq*c-froot)/(fnsq*c+froot)
0102           r22=(c-froot)/(c+froot)
0103           go to 105
0104      c
0105      102  ir=2
0106           fnsq=zone+m11
0107           froot=cdsqrt(csq+m11+m13**2/fnsq)
0108           go to 106
0109      103  com1=(s*froot+m13)/(s*fnsq+m13)
0110           r11=(c-com1)/(c+com1)
0111           ir=3
0112           froot=cdsqrt(csq+m22)
0113           go to 106
0114      104  r22=(c-froot)/(c+froot)
0115      105  r12=(1.d-20,0.d0)
0116           r21=(1.d-20,0.d0)
0117           go to 40
0118      c
0119      106  if(dimag(froot) .gt. 0.d0) froot=-froot
0120           if(ir-2) 101,103,104
0121      c
0122      201  format(' for theta=',f7.4,f9.4,' q=',1p2e11.3,
0123      $      ' poynting(z)=',e11.3)
0124      202  format(/4x,'ht',7x,'delh')
0125      end

```

```

0001      subroutine integ
0002      implicit real *8 (a-h,o-z)
0003      c
0004      include 'common1.for'
0020      include 'common2.for'
0034      include 'common3.for'
0059      c
0060      real*8 logr0
0061      integer sflag
0062      dimension logr0(8), dlr0(8), dlogr0(8), dlogr1(8), dlogr2(8)
0063      data dlhmin/1.953125d-3/,dlgrmx/1.d20/
0064      c
0065      factor=10.d0**(-prec)
0066      emax=factor*3.d0
0067      emin=factor*.3d0
0068      ht=topht
0069      lht=lhtmn
0070      mht=mhtmn
0071      delh=3.125d-2
0072      svdelh=delh
0073      if(debug .gt. 2) print 200,theta
0074      call smtrix
0075      c
0076      c      runge kutta
0077      10      sflag=0
0078              if(debug .gt. 2) print 201
0079      11      if(lht .lt. lthmx .and. ht .le. htlist(lht+1)) then
0080              lht=lht+1
0081              go to 11
0082      end if
0083      13      if(mht .lt. mthmx .and. ht .le. hclist(mht+1)) then
0084              mht=mht+1
0085              go to 13
0086      end if
0087      if(ht-delh .lt. htlist(lht+1)) then
0088          sflag=1
0089          saveht=htlist(lht+1)
0090          delh=ht-saveht
0091      end if
0092      if(ht-delh .lt. d) then
0093          sflag=1
0094          saveht=d
0095          delh=ht-saveht
0096      end if
0097      do 30 i=1,8
0098          logr0(i)=logr(i)
0099      30      dlr0(i)=dlr0(i)
0100      c
0101      c      Try again
0102      40      do 50 i=1,8
0103          dlogr0(i)=-dlr0(i)*delh
0104      50      logr(i)=logr0(i)+0.5d0*dlogr0(i)
0105          ht=ht-0.5d0*delh
0106          call smtrix
0107          do 60 i=1,8
0108              dlr0(i)=dsign(dmin1(dlgrmx,dabs(dlr0(i))),dlr0(i))
0109              dlogr1(i)=-dlr0(i)*delh

```

# INTEG

```

0110      60      logr(i)=logr0(i)+0.5d0*dlogr1(i)
0111          call rderiv
0112          do 70 i=1,8
0113              dlrhd(i)=dsign(dmin1(dlgrmx,dabs(dlrhd(i))),dlrhd(i))
0114              dlogr2(i)=-dlrhd(i)*delh
0115      70      logr(i)=logr0(i)+dlogr2(i)
0116          ht=ht-0.5d0*delh
0117          call smtrix
0118          error=0.d0
0119          do 80 i=1,8
0120              dlrhd(i)=dsign(dmin1(dlgrmx,dabs(dlrhd(i))),dlrhd(i))
0121              dlogr4=((-dlrhd(i)*delh+dlogr0(i))/2.d0+dlogr1(i)+dlogr2(i))/3.d0
0122              logr(i)=logr0(i)+dlogr4
0123      80      error=error+(dlogr2(i)-dlogr4)**2
0124          error=dsqrt(error/8.d0)
0125          if(error .lt. emax .or. delh .le. dlhmin) go to 100
0126          sflag=0
0127          ht=ht+delh
0128          delh=0.5d0*delh
0129          if(delh .lt. dlhmin) delh=dlhmin
0130          go to 40
0131      100      call rderiv
0132          if(error .lt. emin) delh=2.*delh
0133          if(sflag .eq. 1) then
0134              delh=svdelh
0135              ht=saveht
0136          end if
0137          svdelh=delh
0138          if(ht .gt. d) go to 10
0139          return
0140      c
0141      200      format(/' DEBUG:  theta =',2f9.4)
0142      201      format(' ')
0143          end

```

```

0001      subroutine iterat
0002      implicit real *8 (a-h,o-z)
0003      c
0004      c      This routine drives the iteration to obtain solutions to the
0005      c      modal equation.
0006      c
0007      include 'common2.for'
0021      include 'common3.for'
0046      c
0047      complex*16 theta0,f0,dlthta
0048      real*4 absr,absi
0049      c
0050      nriter=0
0051      if(debug .gt. 1) then
0052          if(rpoly .eq. 0) then
0053              print 300
0054          else
0055              print 301
0056          end if
0057          print 302
0058      end if
0059      c      Store the starting angle
0060      theta0=theta
0061      10      theta=theta-dthta
0062          call comp f
0063          f0=f
0064          theta=theta+dthta
0065          call comp f
0066      c      Store the magnitude of the f-function for the starting angle
0067      if(nriter .eq. 0) fmag0=cdabs(f)
0068      nriter=nriter+1
0069      dfdtht=(f-f0)/dthta
0070      dlthta=-f/dfdtht
0071      if(debug .gt. 1) then
0072          fmag=cdabs(f)
0073          print 303,theta,fmag,dlthta,dfdtht
0074      end if
0075      c
0076      absr=dabs(dreal(dlthta))
0077      absi=dabs(dimag(dlthta))
0078      if(absr .gt. thtinc) dlthta=dlthta*(thtinc/absr)
0079      if(absi .gt. thtinc) dlthta=dlthta*(thtinc/absi)
0080      theta=theta+dlthta
0081      if(nriter .lt. maxitr .and.
0082      $ (absr .gt. lub(1) .or. absi .gt. lub(2))) go to 10
0083      c
0084      nriter=nriter+1
0085      f0=f
0086      call comp f
0087      dfdtht=(f-f0)/dlthta
0088      if(debug .gt. 1) then
0089          fmag=cdabs(f)
0090          dlthta=zero
0091          print 303,theta,fmag,dlthta,dfdtht
0092      end if
0093      if(rpoly .eq. 1) then
0094      c      Test the magnitude of the f-function of the final angle

```

# ITERAT

```

0095      fmag=cdabs(f)
0096      if(fmag .gt. fmag0) then
0097          print 304,fmag0,fmag
0098          theta=theta0
0099      end if
0100  end if
0101  if(typitr .gt. 0) then
0102      if(typitr .eq. 1) then
0103          dfdtht=(rbar22*r22-zone)*dfdtht
0104      else
0105          dfdtht=(rbar11*r11-zone)*dfdtht
0106      end if
0107  end if
0108  return
0109  300  format('0Iterations:  exact')
0110  301  format('0Iterations:  inexact')
0111  302  format(8x,'real      imag      f mag      d real      d imag',5x,
0112  $      'dfdt real  dfdt imag')
0113  303  format(5x,2f8.4,1pe12.3,2(1x,2e11.3))
0114  304  format(' Warning ITERAT:  During RPOLY=1, starting fmag (',
0115  $      1pe10.4,') is smaller than final fmag (',1pe10.4,')')
0116      end

```

```

0001      subroutine mdhnl (z,h1,h2,h1prme,h2prme,theta,idbg)
0002      c
0003      implicit complex*16 (a-h,o-z)
0004      complex*16 i,mpower,mterm
0005      real*8 a,b,c,d,cap,part1,part2,zmag
0006      character*4 idbg
0007      dimension a(30), b(30), c(30), d(30), cap(30), part1(2), part2(2)
0008      equivalence (part1,term4), (part2,sum4)
0009      data a / 9.3043671692922944819d-01, 3.1014557230974314911d+01,
0010      $ 2.0676371487316209897d+02, 5.7434365242545027449d+02,
0011      $ 8.7021765519007617234d+02, 8.2877871922864397320d+02,
0012      $ 5.4168543740434246542d+02, 2.5794544638302022111d+02,
0013      $ 9.3458495066311674231d+01, 2.6626351870744066662d+01,
0014      $ 6.1210004300561072794d+00, 1.1592803844803233472d+00,
0015      $ 1.8401275944132116616d-01, 2.4833030963741048003d-02,
0016      $ 2.8842080097260218300d-03, 2.9133414239656786138d-04,
0017      $ 2.5827494893312753646d-05, 2.0256858739853140063d-06,
0018      $ 1.4155736366074870734d-07, 8.8695090013000443124d-09,
0019      $ 5.0110220346327933889d-10, 2.5658074934115685526d-11,
0020      $ 1.1961806496091228666d-12, 5.0988092481207283185d-14,
0021      $ 1.9948392989517716388d-15, 7.1886100863126905797d-17,
0022      $ 2.3938095525516785112d-18, 7.3883010881224645255d-20,
0023      $ 2.1194208514407528762d-21, 5.6653858632471341093d-23/
0024      data b / 6.7829872514427588456d-01, 1.1304978752404598033d+01,
0025      $ 5.383232154307609704d+01, 1.1962940478735024376d+02,
0026      $ 1.5337103177865415841d+02, 1.2780919314887846509d+02,
0027      $ 7.4742218215718400631d+01, 3.2355938621523117060d+01,
0028      $ 1.0785312873841039006d+01, 2.8532573740320209005d+00,
0029      $ 6.1360373635097223595d-01, 1.0937678009821251966d-01,
0030      $ 1.6422939954686564465d-02, 2.1055051223957133911d-03,
0031      $ 2.3316778764072130571d-04, 2.2528288660939256561d-05,
0032      $ 1.9156708045016374595d-06, 1.4446989475879618839d-07,
0033      $ 9.7286124416697769730d-09, 5.8854279743918795891d-10,
0034      $ 3.2160808603234314644d-11, 1.5952782045255116351d-12,
0035      $ 7.2151886229105003778d-14, 2.9876557444763976717d-15,
0036      $ 1.1368553061173507104d-16, 3.9889659863766691603d-18,
0037      $ 1.2946984700995355913d-19, 3.8985199340546088228d-21,
0038      $ 1.0920223904914870636d-22, 2.8527230681595795812d-24/
0039      data c / 4.6521835846461472410d-01, 6.2029114461948629822d+00,
0040      $ 2.5845464359145262382d+01, 5.2213059311404570392d+01,
0041      $ 6.2158403942148298012d+01, 4.8751689366390821897d+01,
0042      $ 2.7084271870217123228d+01, 1.1215019407957400909d+01,
0043      $ 3.5945575025504490022d+00, 9.1815006450841609147d-01,
0044      $ 1.9128126343925335199d-01, 3.3122296699437809740d-02,
0045      $ 4.8424410379295043444d-03, 6.0568368204246458321d-04,
0046      $ 6.5550182039227768583d-05, 6.1985987743950608612d-06,
0047      $ 5.1654989786625507119d-07, 3.8220488188402150986d-08,
0048      $ 2.5278100653705126277d-09, 1.5033066103898380141d-10,
0049      $ 8.0822936042464409157d-12, 3.9473961437101054471d-13,
0050      $ 1.7590891906016512675d-14, 7.1814214762263778920d-16,
0051      $ 2.6957287823672589641d-17, 9.3358572549515461865d-19,
0052      $ 2.9922619406895981315d-20, 8.9015675760511620701d-22,
0053      $ 2.4644428505125033375d-23, 6.3656020935361057409d-25/
0054      data d / 6.7829872514427588456d-01, 4.5219915009618392131d+01,
0055      $ 3.7683262508015326776d+02, 1.1962940478735024344d+03,
0056      $ 1.9938234131225040548d+03, 2.0449470903820554375d+03,
0057      $ 1.4201021460986496090d+03, 7.1183064967350857463d+02,

```

```

00058      $      2.6963282184602597492d+02, 7.989120647289005511d+01,
00059      $      1.9021715826880139294d+01, 3.7188105233392256682d+00,
00060      $      6.0764877832340288572d-01, 8.4220204895828535644d-02,
00061      $      1.0026214868551016149d-02, 1.0363012784032058021d-03,
00062      $      9.3867869420580235442d-05, 7.5124345274574017960d-06,
00063      $      5.3507368429183773360d-07, 3.4135482251472901638d-08,
00064      $      1.9618093247972931935d-09, 1.0209780508963274472d-10,
00065      $      4.8341763773500352579d-12, 2.0913590211334783723d-13,
00066      $      8.2990437346566602039d-15, 3.0316141496462685641d-16,
00067      $      1.0228117913786331176d-17, 3.1967863459247792364d-19,
00068      $      9.2821903191776400453d-21, 2.5103962999804300309d-22/
00069      data cap / 1.0416666666666666663d-01, 8.3550347222222222116d-02,
00070      $      1.2822657455632716019d-01, 2.9184902646414046315d-01,
00071      $      8.8162726744375764874d-01, 3.3214082818627675264d+00,
00072      $      1.4995762986862554546d+01, 7.8923013011586517530d+01,
00073      $      4.7445153886826431887d+02, 3.2074900908906619004d+03,
00074      $      2.4086549640874004605d+04, 1.9892311916950979121d+05,
00075      $      1.7919020077753438063d+06, 1.7484377180034121023d+07,
00076      $      1.8370737967633072978d+08, 2.0679040329451551508d+09,
00077      $      2.4827519375935888472d+10, 3.1669454981734887315d+11,
00078      $      4.2771126865134715582d+12, 6.0971132411392560749d+13,
00079      $      9.1486942234356396792d+14, 1.4413525170009350101d+16,
00080      $      2.3788844395175757942d+17, 4.1046081600946921885d+18,
00081      $      7.3900049415704853993d+19, 1.3859220004603943141d+21,
00082      $      2.7030825930275761623d+22, 5.4747478619645573335d+23,
00083      $      1.1498937014386333524d+25, 2.5014180692753603969d+26/
00084      data i/(0.d0,1.d0)/
00085      data one/(1.d0,0.d0)/,two/(2.d0,0.d0)/,zero/(0.d0,0.d0)/
00086      data root3/(1.73205080756888d0,0.d0)/
00087      data alpha/(8.53667218838951d-1,0.d0)/
00088      data const1/( 2.58819045102522d-01,-9.65925826289067d-01)/
00089      data const2/( 2.58819045102522d-01, 9.65925826289067d-01)/
00090      data const3/(-9.65925826289067d-01, 2.58819045102522d-01)/
00091      data const4/(-9.65925826289067d-01,-2.58819045102522d-01)/
00092      c
00093      zpower=one
00094      sum3=zero
00095      sum4=zero
00096      zmag=cdabs(z)
00097      if(zmag .gt. 6.1d0) go to 70
00098      sum1=zero
00099      sum2=zero
00100      zterm=-z**3/(200.d0,0.d0)
00101      do 50 m=1,30
00102      sum1=sum1+dcmplx(a(m),0.d0)*zpower
00103      sum2=sum2+dcmplx(b(m),0.d0)*zpower
00104      sum3=sum3+dcmplx(c(m),0.d0)*zpower
00105      term4=dcmplx(d(m),0.d0)*zpower
00106      sum4=sum4+term4
00107      if(dabs(part1(1)) .le. 1.d-17*dabs(part2(1)) .and.
00108      $ dabs(part1(2)) .le. 1.d-17*dabs(part2(2))) go to 60
00109      50 zpower=zpower*zterm
00110      60 gm2f=i*(z*sum2-two*sum1)/root3
00111      gpmfp=i*(sum4+two*z*z*sum3)/root3
00112      h1=z*sum2+gm2f
00113      h2=h1-two*gm2f
00114      h1prme=sum4+gpmfp

```



## MDHNKL

```

0115      h2prme=h1prme-two*gpmfp
0116      go to 999
0117  70    mpower=one
0118      sum1=one
0119      sum2=one
0120      rtz=cdsqrt(z)
0121      sqrtzb=rtz*z
0122      zterm=i/sqrtzb
0123      mterm=-zterm
0124      dm=zero
0125      term3=one
0126      do 80 m=1,30
0127          zpower=zpower*zterm
0128          mpower=mpower*mterm
0129          dm=dm+one
0130          term1=dcplx(cap(m),0.d0)*zpower
0131          term2=dcplx(cap(m),0.d0)*mpower
0132          if(cdabs(term2/term3) .ge. 1.d0) go to 81
0133          sum1=sum1+term1
0134          sum2=sum2+term2
0135          sum3=sum3+dm*term1
0136          term4=dm*term2
0137          sum4=sum4+term4
0138          if(dabs(part1(1)/part2(1)) .le. 1.d-17 .and.
0139  $      dabs(part1(2)/part2(2)) .le. 1.d-17) go to 81
0140  80    term3=term2
0141  81    zterm=(-1.5d0,0.d0)/z
0142          sum3=sum3*zterm
0143          sum4=sum4*zterm
0144          term1=(-0.25d0,0.d0)-i*sqrtzb)/z
0145          term2=(-0.25d0,0.d0)+i*sqrtzb)/z
0146          exp1=cexp((0.d0,0.66666666666666666667d0)*sqrtzb)
0147          exp2=const1*exp1
0148          exp3=const2/exp1
0149          exp4=const3*exp1
0150          exp5=const4/exp1
0151          zterm=alpha/cdsqrt(rtz)
0152          term4=z
0153          if(part1(1) .ge. 0.d0 .or. part1(2) .ge. 0.d0) go to 90
0154          h1=zterm*(exp2*sum2+exp5*sum1)
0155          h1prme=zterm*(exp2*(sum2*term2+sum4)+exp5*(sum1*term1+sum3))
0156          go to 110
0157  90    h1=zterm*exp2*sum2
0158          h1prme=zterm*exp2*(sum2*term2+sum4)
0159  110   if(part1(1) .ge. 0.d0 .or. part1(2) .lt. 0.d0) go to 120
0160          h2=zterm*(exp3*sum1+exp4*sum2)
0161          h2prme=zterm*(exp3*(sum1*term1+sum3)+exp4*(sum2*term2+sum4))
0162          go to 999
0163  120   h2=zterm*exp3*sum1
0164          h2prme=zterm*exp3*(sum1*term1+sum3)
0165  c      calculate wronskian as partial check on validity
0166  999   sum4=h1*h2prme-h1prme*h2
0167          if(dabs(part2(1)) .le. 1.d-8 .and.
0168  $      dabs(part2(2)+1.457495441040461d0) .le. 1.d-8) go to 1000
0169          print 1001,sum4,theta,idbg
0170  1000   return
0171  1001   format(' ***** possible error in mdhnkl:  w = ',1p2e15.6,

```

MDHNKL

0172  
0173

\$ ' for theta = ',Op2f10.4,' at ',a4)  
end

```

0001      subroutine newmag(j,r,phi,j,thet,bmf,dip,b,br,bp,bt)
0002      c
0003      Returns parameters of the geomagnetic field
0004      c
0005      Input:  J=0:  Use spherical earth
0006              J=1:  Use spheroidal earth
0007              R    is altitude in km
0008              PHIJ is West longitude in radians
0009              THET is co-latitude in radians
0010      c
0011      Output: BMF is declination of the geomagnetic field
0012              DIP is dip angle
0013              B   is total field
0014              BR  is radial component
0015              BP  is longitudinal component
0016              BT  is latitudinal component
0017      c
0018      dimension g(10,10), bm(10)
0019      data g/.0,3.032193e04,2.522093e03,-3.285459e03,-4.170639e03,1.6928
0020      $19e03,-6.684202e02,-1.900312e03,-2.405232e02,-9.358495e02,-5.75507
0021      $0e03,2.131549e03,-5.206994e03,6.237642e03,-4.496227e03,-3.650850e0
0022      $3,-1.241578e03,2.029996e03,-4.463745e02,-3.659410e02,3.495705e03,-
0023      $1.085898e02,-1.369823e03,-2.514676e03,-1.943789e03,-1.836598e03,-1
0024      $ .313045e02,-1.626874e02,4.917246e02,-8.068787e02,1.220352e03,-4.75
0025      $3192e02,1.392784e02,-6.836385e02,8.297622e02,1.568303e02,2.302497e
0026      $03,-1.540896e02,5.700617e02,1.292881e03,-7.922399e02,1.080333e03,-
0027      $3.941087e01,2.055201e02,-1.853181e02,3.569555e02,-3.656370e01,3.01
0028      $2583e02,8.903696e01,-6.436587e02,-2.424140e02,-1.041800e03,5.89817
0029      $9e02,2.310479e02,-5.887414e01,4.001436e01,-1.209943e-02,9.459898e0
0030      $0,-1.050984e02,-3.745591e02,3.563806e02,-1.545264e03,-6.828717e02,
0031      $1.681499e02,2.971388e01,6.276772e00,7.309118e01,-3.402882e01,3.871
0032      $370e01,-1.670375e01,1.915876e03,7.079673e02,1.857451e02,-2.732077e
0033      $01,-1.705171e02,5.115862e01,1.302727e01,-3.776955e00,-2.940332e01,
0034      $3.510623e-01,-4.633602e02,6.821298e02,-2.394838e02,4.549622e02,-3.
0035      $794850e01,-1.617146e02,6.268821e00,1.004341e01,-4.002399e00,-4.152
0036      $194e00,2.803131e03,-1.698787e03,-4.244406e02,1.998351e02,6.192396e
0037      $01,-1.668931e02,-9.080082e01,-5.963821e-01,1.524572e00,-9.238670e-
0038      $01/
0039      data bm/9.933492e04,9.933492e04,3.746322e04,2.457753e04,1.329481e0
0040      $4,6.468820e03,3.385349e03,1.616258e03,7.409154e02,3.641040e02/
0041      data nmax/10/,berr/0.0001/
0042      c
0043      50      p22=abs(sin(thet))
0044              if(p22 .eq. 0.) p22=1.e-6
0045              p21=sqrt(1.-p22*p22)
0046              re=6356.912+p22*p22*(21.3677+.108*p22*p22)
0047              ar=(re+r)/6371.2
0048              if(thet .le. 1.570796327e0) go to 70
0049              p21=-p21
0050      70      if(j .eq. 0) go to 90
0051              ssq=p22*p22
0052              ar=ar+(14.288-ssq*(21.3677+.108*ssq))/6371.2
0053      90      ar=1./ar
0054      c      n= 2
0055              dp22=p21
0056      c      convert to east longitude
0057              phi=phi+j

```

NEWMAG

```

0058      if(phi) 92,96,94
0059      92      phi=-phi
0060              go to 96
0061      94      phi=6.2831853e0-phi
0062      96      sp2=sin(phi)
0063              sp2=sin(phi)
0064              cp2=cos(phi)
0065              dp21=-p22
0066              aor=aor*ar*ar
0067              c2=g(2,2)*cp2+g(1,2)*sp2
0068              br=-(aor+aor)*(g(2,1)*p21+c2*p22)
0069              bt=aor*(g(2,1)*dp21+c2*dp22)
0070              bp=aor*(g(1,2)*cp2-g(2,2)*sp2)*p22
0071              if(nmax .lt. 3) go to 260
0072              aor=aor*ar
0073              err=berr*sqrt((bp/p22)**2+br**2+bt**2)
0074              if(bm(3)*aor .le. err) go to 260
0075              sp3=(sp2+sp2)*cp2
0076              cp3=(cp2+sp2)*(cp2-sp2)
0077              p31=p21*p21-0.33333333e0
0078              p32=p21*p22
0079              p33=p22*p22
0080              dp31=-p32-p32
0081              dp32=p21*p21-p33
0082              dp33=-dp31
0083              c2=g(3,2)*cp2+g(1,3)*sp2
0084              c3=g(3,3)*cp3+g(2,3)*sp3
0085              br=br-3.0*aor*(g(3,1)*p31+c2*p32+c3*p33)
0086              bt=bt+aor*(g(3,1)*dp31+c2*dp32+c3*dp33)
0087              bp=bp-aor*((g(3,2)*sp2-g(1,3)*cp2)*p32+2.0*(g(3,3)*sp3-g(2,3)*cp3)
0088              $*p33)
0089      c      n= 4
0090              if(nmax .lt. 4) go to 260
0091              aor=aor*ar
0092              if(bm(4)*aor .le. err) go to 260
0093              sp4=sp2*cp3+cp2*sp3
0094              cp4=cp2*cp3-sp2*sp3
0095              p41=p21*p31-0.26666666e0*p21
0096              dp41=p21*dp31+dp21*p31-0.26666666e0*dp21
0097              p42=p21*p32-0.20000000e0*p22
0098              dp42=p21*dp32+dp21*p32-0.20000000e0*dp22
0099              p43=p21*p33
0100              dp43=p21*dp33+dp21*p33
0101              p44=p22*p33
0102              dp44=3.0*p43
0103              c2=g(4,2)*cp2+g(1,4)*sp2
0104              c3=g(4,3)*cp3+g(2,4)*sp3
0105              c4=g(4,4)*cp4+g(3,4)*sp4
0106              br=br-4.0*aor*(g(4,1)*p41+c2*p42+c3*p43+c4*p44)
0107              bt=bt+aor*(g(4,1)*dp41+c2*dp42+c3*dp43+c4*dp44)
0108              bp=bp-aor*((g(4,2)*sp2-g(1,4)*cp2)*p42+2.0*(g(4,3)*sp3-g(2,4)*cp3)
0109              $*p43+3.0*(g(4,4)*sp4-g(3,4)*cp4)*p44)
0110              if(nmax .lt. 5) go to 260
0111              aor=aor*ar
0112              if(bm(5)*aor .le. err) go to 260
0113              sp5=(sp3+sp3)*cp3
0114              cp5=(cp3+sp3)*(cp3-sp3)

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0115      p51=p21*p41-0.25714285e0*p31
0116      p52=p21*p42-0.22857142e0*p32
0117      dp51=p21*dp41+dp21*p41-0.25714285e0*dp31
0118      dp52=p21*dp42+dp21*p42-0.22857142e0*dp32
0119      p53=p21*p43-0.14285714e0*p33
0120      dp53=p21*dp43+dp21*p43-0.14285714e0*dp33
0121      p54=p21*p44
0122      dp54=p21*dp44+dp21*p44
0123      p55=p22*p44
0124      dp55=4.0*p54
0125      c2=g(5,2)*cp2+g(1,5)*sp2
0126      c3=g(5,3)*cp3+g(2,5)*sp3
0127      c4=g(5,4)*cp4+g(3,5)*sp4
0128      c5=g(5,5)*cp5+g(4,5)*sp5
0129      br=br-5.0*aor*(g(5,1)*p51+c2*p52+c3*p53+c4*p54+c5*p55)
0130      bt=bt+aor*(g(5,1)*dp51+c2*dp52+c3*dp53+c4*dp54+c5*dp55)
0131      bp=bp-aor*((g(5,2)*sp2-g(1,5)*cp2)*p52+2.0*(g(5,3)*sp3-g(2,5)*cp3)
0132      $*p53+3.0*(g(5,4)*sp4-g(3,5)*cp4)*p54+4.0*(g(5,5)*sp5-g(4,5)*cp5)*p
0133      $55)
0134      c      n= 6
0135      if(nmax .lt. 6) go to 260
0136      aor=aor*ar
0137      if(bm(6)*aor .le. err) go to 260
0138      sp6=sp2*cp5+cp2*sp5
0139      cp6=cp2*cp5-sp2*sp5
0140      p61=p21*p51-0.25396825e0*p41
0141      dp61=p21*dp51+dp21*p51-0.25396825e0*dp41
0142      p62=p21*p52-0.23809523e0*p42
0143      dp62=p21*dp52+dp21*p52-0.23809523e0*dp42
0144      p63=p21*p53-0.19047619e0*p43
0145      dp63=p21*dp53+dp21*p53-0.19047619e0*dp43
0146      p64=p21*p54-0.11111111e0*p44
0147      dp64=p21*dp54+dp21*p54-0.11111111e0*dp44
0148      p65=p21*p55
0149      dp65=p21*dp55+dp21*p55
0150      p66=p22*p55
0151      dp66=5.0*p65
0152      c2=g(6,2)*cp2+g(1,6)*sp2
0153      c3=g(6,3)*cp3+g(2,6)*sp3
0154      c4=g(6,4)*cp4+g(3,6)*sp4
0155      c5=g(6,5)*cp5+g(4,6)*sp5
0156      c6=g(6,6)*cp6+g(5,6)*sp6
0157      br=br-6.0*aor*(g(6,1)*p61+c2*p62+c3*p63+c4*p64+c5*p65+c6*p66)
0158      bt=bt+aor*(g(6,1)*dp61+c2*dp62+c3*dp63+c4*dp64+c5*dp65+c6*dp66)
0159      bp=bp-aor*((g(6,2)*sp2-g(1,6)*cp2)*p62+2.0*(g(6,3)*sp3-g(2,6)*cp3)
0160      $*p63+3.0*(g(6,4)*sp4-g(3,6)*cp4)*p64+4.0*(g(6,5)*sp5-g(4,6)*cp5)*p
0161      $65+5.0*(g(6,6)*sp6-g(5,6)*cp6)*p66)
0162      if(nmax .lt. 7) go to 260
0163      aor=aor*ar
0164      if(bm(7)*aor .le. err) go to 260
0165      sp7=(sp4+sp4)*cp4
0166      cp7=(cp4+sp4)*(cp4-sp4)
0167      p71=p21*p61-0.25252525e0*p51
0168      dp71=p21*dp61+dp21*p61-0.25252525e0*dp51
0169      p72=p21*p62-0.24242424e0*p52
0170      dp72=p21*dp62+dp21*p62-0.24242424e0*dp52
0171      p73=p21*p63-0.21212121e0*p53

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0172      dp73=p21*dp63+dp21*p63-0.21212121e0*dp53
0173      p74=p21*p64-0.16161616e0*p54
0174      dp74=p21*dp64+dp21*p64-0.16161616e0*dp54
0175      p75=p21*p65-0.09090909e0*p55
0176      dp75=p21*dp65+dp21*p65-0.09090909e0*dp55
0177      p76=p21*p66
0178      dp76=p21*dp66+dp21*p66
0179      p77=p22*p66
0180      dp77=6.0*p76
0181      c2=g(7,2)*cp2+g(1,7)*sp2
0182      c3=g(7,3)*cp3+g(2,7)*sp3
0183      c4=g(7,4)*cp4+g(3,7)*sp4
0184      c5=g(7,5)*cp5+g(4,7)*sp5
0185      c6=g(7,6)*cp6+g(5,7)*sp6
0186      c7=g(7,7)*cp7+g(6,7)*sp7
0187      br=br-7.0*aor*(g(7,1)*p71+c2*p72+c3*p73+c4*p74+c5*p75+c6*p76+c7*p7
0188      $7)
0189      bt=bt+aor*(g(7,1)*dp71+c2*dp72+c3*dp73+c4*dp74+c5*dp75+c6*dp76+c7*
0190      $dp77)
0191      bp=bp-aor*((g(7,2)*sp2-g(1,7)*cp2)*p72+2.0*(g(7,3)*sp3-g(2,7)*cp3)
0192      $*p73+3.0*(g(7,4)*sp4-g(3,7)*cp4)*p74+4.0*(g(7,5)*sp5-g(4,7)*cp5)*p
0193      $75+5.0*(g(7,6)*sp6-g(5,7)*cp6)*p76+6.0*(g(7,7)*sp7-g(6,7)*cp7)*p77
0194      $)
0195      c      n= 8
0196      if(nmax.lt. 8) go to 260
0197      aor=aor*ar
0198      if(bm(8)*aor.le. err) go to 260
0199      sp8=sp2*cp7+cp2*sp7
0200      cp8=cp2*cp7-sp2*sp7
0201      p81=p21*p71-0.25174825e0*p61
0202      dp81=p21*dp71+dp21*p71-0.25174825e0*dp61
0203      p82=p21*p72-0.24475524e0*p62
0204      dp82=p21*dp72+dp21*p72-0.24475524e0*dp62
0205      p83=p21*p73-0.22377622e0*p63
0206      dp83=p21*dp73+dp21*p73-0.22377622e0*dp63
0207      p84=p21*p74-0.18881118e0*p64
0208      dp84=p21*dp74+dp21*p74-0.18881118e0*dp64
0209      p85=p21*p75-0.13986013e0*p65
0210      dp85=p21*dp75+dp21*p75-0.13986013e0*dp65
0211      p86=p21*p76-0.07692307e0*p66
0212      dp86=p21*dp76+dp21*p76-0.07692307e0*dp66
0213      p87=p21*p77
0214      dp87=p21*dp77+dp21*p77
0215      p88=p22*p77
0216      dp88=7.0*p87
0217      c2=g(8,2)*cp2+g(1,8)*sp2
0218      c3=g(8,3)*cp3+g(2,8)*sp3
0219      c4=g(8,4)*cp4+g(3,8)*sp4
0220      c5=g(8,5)*cp5+g(4,8)*sp5
0221      c6=g(8,6)*cp6+g(5,8)*sp6
0222      c7=g(8,7)*cp7+g(6,8)*sp7
0223      c8=g(8,8)*cp8+g(7,8)*sp8
0224      br=br-8.0*aor*(g(8,1)*p81+c2*p82+c3*p83+c4*p84+c5*p85+c6*p86+c7*p8
0225      17+c8*p88)
0226      bt=bt+aor*(g(8,1)*dp81+c2*dp82+c3*dp83+c4*dp84+c5*dp85+c6*dp86+c7*
0227      $dp87+c8*dp88)
0228      bp=bp-aor*((g(8,2)*sp2-g(1,8)*cp2)*p82+2.0*(g(8,3)*sp3-g(2,8)*cp3)

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0229 $*p83+3.0*(g(8,4)*sp4-g(3,8)*cp4)*p84+4.0*(g(8,5)*sp5-g(4,8)*cp5)*p
0230 $85+5.0*(g(8,6)*sp6-g(5,8)*cp6)*p86+6.0*(g(8,7)*sp7-g(6,8)*cp7)*p87
0231 $+7.0*(g(8,8)*sp8-g(7,8)*cp8)*p88)
0232 if(nmax.lt. 9) go to 260
0233 aor=aor*ar
0234 if(bm(9)*aor.le. err) go to 260
0235 sp9=(sp5+sp5)*cp5
0236 cp9=(cp5+sp5)*(cp5-sp5)
0237 p91=p21*p81-0.25128205e0*p71
0238 dp91=p21*dp81+dp21*p81-0.25128205e0*dp71
0239 p92=p21*p82-0.24615384e0*p72
0240 dp92=p21*dp82+dp21*p82-0.24615384e0*dp72
0241 p93=p21*p83-0.23076923e0*p73
0242 dp93=p21*dp83+dp21*p83-0.23076923e0*dp73
0243 p94=p21*p84-0.20512820e0*p74
0244 dp94=p21*dp84+dp21*p84-0.20512820e0*dp74
0245 p95=p21*p85-0.16923076e0*p75
0246 dp95=p21*dp85+dp21*p85-0.16923076e0*dp75
0247 p96=p21*p86-0.12307692e0*p76
0248 dp96=p21*dp86+dp21*p86-0.12307692e0*dp76
0249 p97=p21*p87-0.06666666e0*p77
0250 dp97=p21*dp87+dp21*p87-0.06666666e0*dp77
0251 p98=p21*p88
0252 dp98=p21*dp88+dp21*p88
0253 p99=p22*p88
0254 dp99=8.0*p98
0255 c2=g(9,2)*cp2+g(1,9)*sp2
0256 c3=g(9,3)*cp3+g(2,9)*sp3
0257 c4=g(9,4)*cp4+g(3,9)*sp4
0258 c5=g(9,5)*cp5+g(4,9)*sp5
0259 c6=g(9,6)*cp6+g(5,9)*sp6
0260 c7=g(9,7)*cp7+g(6,9)*sp7
0261 c8=g(9,8)*cp8+g(7,9)*sp8
0262 c9=g(9,9)*cp9+g(8,9)*sp9
0263 br=br-9.0*aor*(g(9,1)*p91+c2*p92+c3*p93+c4*p94+c5*p95+c6*p96+c7*p9
0264 $7+c8*p98+c9*p99)
0265 bt=bt+aor*(g(9,1)*dp91+c2*dp92+c3*dp93+c4*dp94+c5*dp95+c6*dp96+c7*
0266 $dp97+c8*dp98+c9*dp99)
0267 bp=bp-aor*((g(9,2)*sp2-g(1,9)*cp2)*p92+2.0*(g(9,3)*sp3-g(2,9)*cp3)
0268 $*p93+3.0*(g(9,4)*sp4-g(3,9)*cp4)*p94+4.0*(g(9,5)*sp5-g(4,9)*cp5)*p
0269 $95+5.0*(g(9,6)*sp6-g(5,9)*cp6)*p96+6.0*(g(9,7)*sp7-g(6,9)*cp7)*p97
0270 $+7.0*(g(9,8)*sp8-g(7,9)*cp8)*p98+8.0*(g(9,9)*sp9-g(8,9)*cp9)*p99)
0271 c n=10
0272 if(nmax.lt. 10) go to 260
0273 aor=aor*ar
0274 if(bm(10)*aor.le. err) go to 260
0275 sp10=sp2*cp9+cp2*sp9
0276 cp10=cp2*cp9-sp2*sp9
0277 p101=p21*p91-0.25098039e0*p81
0278 dp101=p21*dp91+dp21*p91-0.25098039e0*dp81
0279 p102=p21*p92-0.24705882e0*p82
0280 dp102=p21*dp92+dp21*p92-0.24705882e0*dp82
0281 p103=p21*p93-0.23529411e0*p83
0282 dp103=p21*dp93+dp21*p93-0.23529411e0*dp83
0283 p104=p21*p94-0.21568627e0*p84
0284 dp104=p21*dp94+dp21*p94-0.21568627e0*dp84
0285 p105=p21*p95-0.18823529e0*p85

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0286      dp105=p21*dp95+dp21*p95-0.18823529e0*dp85
0287      p106=p21*p96-0.15294117e0*p86
0288      dp106=p21*dp96+dp21*p96-0.15294117e0*dp86
0289      p107=p21*p97-0.10980392e0*p87
0290      dp107=p21*dp97+dp21*p97-0.10980392e0*dp87
0291      p108=p21*p98-0.05882352e0*p88
0292      dp108=p21*dp98+dp21*p98-0.05882352e0*dp88
0293      p109=p21*p99
0294      dp109=p21*dp99+dp21*p99
0295      p1010=p22*p99
0296      dp1010=9.0*p109
0297      c2=g(10,2)*cp2+g(1,10)*sp2
0298      c3=g(10,3)*cp3+g(2,10)*sp3
0299      c4=g(10,4)*cp4+g(3,10)*sp4
0300      c5=g(10,5)*cp5+g(4,10)*sp5
0301      c6=g(10,6)*cp6+g(5,10)*sp6
0302      c7=g(10,7)*cp7+g(6,10)*sp7
0303      c8=g(10,8)*cp8+g(7,10)*sp8
0304      c9=g(10,9)*cp9+g(8,10)*sp9
0305      c10=g(10,10)*cp10+g(9,10)*sp10
0306      br=br-10.0*aor*(g(10,1)*p101+c2*p102+c3*p103+c4*p104+c5*p105+c6*p1
0307      $06+c7*p107+c8*p108+c9*p109+c10*p1010)
0308      bt=bt+aor*(g(10,1)*dp101+c2*dp102+c3*dp103+c4*dp104+c5*dp105+c6*dp
0309      1106+c7*dp107+c8*dp108+c9*dp109+c10*dp1010)
0310      bp=bp-aor*((g(10,2)*sp2-g(1,10)*cp2)*p102+2.0*(g(10,3)*sp3-g(2,10)
0311      $*cp3)*p103+3.0*(g(10,4)*sp4-g(3,10)*cp4)*p104+4.0*(g(10,5)*sp5-g(4
0312      $,10)*cp5)*p105+5.0*(g(10,6)*sp6-g(5,10)*cp6)*p106+6.0*(g(10,7)*sp7
0313      $-g(6,10)*cp7)*p107+7.0*(g(10,8)*sp8-g(7,10)*cp8)*p108+8.0*(g(10,9)
0314      $*sp9-g(8,10)*cp9)*p109+9.0*(g(10,10)*sp10-g(9,10)*cp10)*p1010)
0315      260      bp=bp/p22*1.e-5
0316      bt=bt*1.e-5
0317      br=br*1.e-5
0318      b=sqrt(br*br+bt*bt+bp*bp)
0319      bh=sqrt(bt*bt+bp*bp)
0320      bmf=3.141592654e0-acos(bt/bh)
0321      if(bp.lt. 0.) bmf=-bmf
0322      dip=acos(bh/b)
0323      if(br.gt. 0.) dip=-dip
0324      return
0325      end

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```

0001      subroutine profin(lu,type,maxhts,nprint,nrspec,lmax,hlist,alogen)
0002      c
0003      c Reads ionospheric profiles
0004      c type=1: electron and ion densities
0005      c       2: collision frequencies
0006      c
0007      integer type
0008      character*80 bcd
0009      dimension hlist(maxhts),alogen(maxhts,3),en(3)
0010      if(type .ne. 2) then
0011          read(lu,1010) bcd
0012          if(nprint .gt. 1) print 1011,bcd
0013      end if
0014      do 202 l=1,maxhts+1
0015          read(lu,1020,end=900) ht,en
0016          if(ht .lt. 0.) then
0017              lmax=l-1
0018              return
0019          end if
0020          if(l .ne. 1 .and. ht .ge. hlist(l-1)) then
0021              print *, 'ERROR PROFIN: Profile heights out of order'
0022              go to 999
0023          end if
0024          hlist(l)=ht
0025          if(type .eq. 1 .and. nrspec .eq. 3) en(3)=en(2)-en(1)
0026          if(nprint .gt. 1) print 1021,ht,(en(k),k=1,nrspec)
0027          do 201 k=1,nrspec
0028      201      alogen(l,k)=alog(amax1(en(k),1.e-20))
0029      202      continue
0030          print *, 'ERROR PROFIN: Too many heights in profile'
0031          go to 999
0032      900      print *, 'ERROR PROFIN: Profile input not properly terminated'
0033      999      lmax=-1
0034          return
0035      1010      format(a80)
0036      1011      format(/1x,a80)
0037      1020      format(f7.2,4x,3e10.2)
0038      1021      format(f8.2,4x,1p3e10.2)
0039      end

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0001      subroutine qartic(q,b3,b2,b1,b0,debug,newq)
0002      implicit real *8 (a-h,o-z)
0003      complex*16 b3,b2,b1,b0,q,b3sq,h,i,g,hprime,gprime,sqroot,
0004      $          p1,p2,cbert0,cbert1,cbert2,omega1,omega2,
0005      $          rootp,rootq,rootr,fncton,ctemp,dfdq,dq
0006      integer debug
0007      dimension diff(4),q(4)
0008      data omega1/(-5.d-1, 8.660254038d-1)/
0009      data omega2/(-5.d-1,-8.660254038d-1)/
0010      data tol/1.d-06/,imax/5/
0011      c
0012      iagain=0
0013      if(newq .eq. 1) go to 30
0014      newq=1
0015      10 b3sq=b3**2
0016      h=b2-b3sq
0017      i=b0-(4.d0,0.d0)*b3*b1+(3.d0,0.d0)*b2**2
0018      g=b1+b3*(-3.d0,0.d0)*b2+(2.d0,0.d0)*b3sq
0019      hprime=-i/(12.d0,0.d0)
0020      gprime=-g**2/(4.d0,0.d0)-h*(h**2+(3.d0,0.d0)*hprime)
0021      c
0022      sqroot=cdsqrt(gprime**2+(4.d0,0.d0)*hprime**3)
0023      p1=(-.5d0,0.d0)*(gprime-sqroot)
0024      p2=(-.5d0,0.d0)*(gprime+sqroot)
0025      if(cdabs(p1) .lt. cdabs(p2)) p1=p2
0026      cbert0=cdexp(cdlog(p1)/(3.d0,0.d0))
0027      cbert1=omega1*cbert0
0028      cbert2=omega2*cbert0
0029      c
0030      rootp=cdsqrt(cbert0-hprime/cbert0-h)
0031      rootq=cdsqrt(cbert1-hprime/cbert1-h)
0032      rootr=cdsqrt(cbert2-hprime/cbert2-h)
0033      if(cdabs(g) .gt. 1.d-30) then
0034          sign=-rootp*rootq*rootr*(2.d0,0.d0)/g
0035          if(sign .lt. 0.d0) rootr=-rootr
0036      end if
0037      q(1)=+rootp+rootq+rootr-b3
0038      q(2)=+rootp-rootq-rootr-b3
0039      q(3)=-rootp+rootq-rootr-b3
0040      q(4)=-rootp-rootq+rootr-b3
0041      c
0042      30 if(debug .gt. 2) print 100,b3,b2,b1,b0
0043      do 60 n=1,4
0044      do 40 iter=1,imax
0045      fncton=((q(n)+(4.d0,0.d0)*b3)*q(n)+(6.d0,0.d0)*b2)*q(n)
0046      $          +(4.d0,0.d0)*b1)*q(n)+b0
0047      dfdq=((4.d0,0.d0)*q(n)+(12.d0,0.d0)*b3)*q(n)
0048      $          +(12.d0,0.d0)*b2)*q(n)+(4.d0,0.d0)*b1
0049      dq=-fncton/dfdq
0050      q(n)=q(n)+dq
0051      testdq=cdabs(dq/q(n))
0052      if(testdq .le. tol) go to 60
0053      40 continue
0054      if(iagain .eq. 1) then
0055          fncton=((q(n)+(4.d0,0.d0)*b3)*q(n)+(6.d0,0.d0)*b2)*q(n)
0056      $          +(4.d0,0.d0)*b1)*q(n)+b0
0057          print 101,n,q(n),fncton,dq,iagain

```

# QARTIC

```

0058          stop
0059      else
0060          iagain=1
0061          go to 10
0062      end if
0063      60      continue
0064      c
0065          l=0
0066          do 80 m=2,4
0067              do 80 n=m,4
0068                  if(dimag(q(n)) .gt. 0.d0) go to 80
0069                  l=l+1
0070                  ctemp=q(n)
0071                  q(n)=q(m-1)
0072                  q(m-1)=ctemp
0073      80      continue
0074                  if(l .eq. 2) go to 99
0075                  do 81 n=1,4
0076                      angq=cdang(q(n))*57.295779513d0
0077                      if(angq .lt. 135.d0) angq=angq+360.d0
0078      81      diff(n)=dabs(angq-315.d0)
0079                      do 82 nm=2,4
0080                          do 82 n=nm,4
0081                              if(diff(n) .gt. diff(nm-1)) go to 82
0082                              temp=diff(n)
0083                              diff(n)=diff(nm-1)
0084                              diff(nm-1)=temp
0085                              ctemp=q(n)
0086                              q(n)=q(nm-1)
0087                              q(nm-1)=ctemp
0088      82      continue
0089      c
0090      99      return
0091      100      format(/' In QARTIC:  b''s =',4(1pe13.4,e12.4))
0092      101      format(8h q root ,i1,2h =,1p2e13.5,3x,10hfunction =,2e13.5,3x,
0093          $          4hdq =,2e13.5,3x,8hiagain =,i1)
0094      end

```

```

0001      subroutine rbars
0002      implicit real *8 (a-h,o-z)
0003      c
0004      include 'common1.for'
0020      include 'common2.for'
0034      include 'common3.for'
0059      c
0060      complex*16 ngsq,sqroot, ratio,ikc,exd,exdsq,z1,z2,
0061      $          p0,h10,h20,h1prm0,h2prm0,caph10,caph20,
0062      $          pd,h1d,h2d,h1prmd,h2prmd,caph1d,caph2d,
0063      $          a1st,a2nd,a3rd,a4th,a1,a2,a3,a4,f1,f2
0064      real*8 kvraot,kvratt,ndsq,n0sq
0065      c
0066      ngsq=dcmplx(dble(epsr),-dble(sigma)/(omega*8.85434d-12))
0067      sqroot=cdsqrt(ngsq-ssq)
0068      c
0069      if(dimag(theta) .lt. -10.d0 .or. alpha .eq. 0.) go to 20
0070      if(d .eq. 0.) go to 10
0071      c
0072      kvraot=dexp(dlog(wn/alpha)/3.d0)
0073      kvratt=kvraot**2
0074      avrkot=1.d0/kvraot
0075      avrktt=avrkot**2*0.5d0
0076      n0sq=1.-alpha*h
0077      ratio=n0sq/ngsq*sqroot
0078      p0=kvratt*(n0sq-ssq)
0079      call mdhnl(p0,h10,h20,h1prm0,h2prm0,theta,'rb 1')
0080      caph10=h1prm0+avrktt*h10
0081      caph20=h2prm0+avrktt*h20
0082      a1st=caph20-zmplxi*ratio*kvraot*h20
0083      a2nd=caph10-zmplxi*ratio*kvraot*h10
0084      a3rd=h2prm0-zmplxi*kvraot*sqroot*h20
0085      a4th=h1prm0-zmplxi*kvraot*sqroot*h10
0086      ndsq=1.-alpha*(h-d)
0087      pd=kvratt*(ndsq-ssq)
0088      call mdhnl(pd,h1d,h2d,h1prmd,h2prmd,theta,'rb 2')
0089      caph1d=h1prmd+avrktt*h1d
0090      caph2d=h2prmd+avrktt*h2d
0091      f1=h2d*a2nd-h1d*a1st
0092      f2=h2d*a4th-h1d*a3rd
0093      a1=c*ndsq*f1
0094      a2=zmplxi*avrkot*(caph1d*a1st-caph2d*a2nd)
0095      a3=zmplxi*avrkot*(h2prmd*a4th-h1prmd*a3rd)
0096      a4=c*f2
0097      rbar11=(a1-a2)/(a1+a2)
0098      rbar22=(a3+a4)/(a4-a3)
0099      hg=exp(-.5*alpha*d)*(h20*a2nd-h10*a1st)/f1
0100      norm11=f1*f1
0101      norm22=f2*f2
0102      norm12=f1*f2
0103      return
0104      c
0105      10  rbar11=(ngsq*c-sqroot)/(ngsq*c+sqroot)
0106          rbar22=(c-sqroot)/(c+sqroot)
0107          hg=zone
0108          norm11=(-2.124292958d0,0.d0)
0109          norm22=norm11

```

# RBARS

```

0110      norm12=norm11
0111      return
0112      c
0113      c      flat earth
0114      20      ikc=dcplx(0.d0,-wn)*c
0115      exd=cexp(ikc*d)
0116      exdsq=exd*exd
0117      z1=(ngsq*c-sqroot)/(ngsq*c+sqroot)
0118      z2=(c-sqroot)/(c+sqroot)
0119      rbar11=z1*exdsq
0120      rbar22=z2*exdsq
0121      hg=exd*(zone+z1)/(zone+rbar11)
0122      norm11=(zone+rbar11)*(zone+rbar11)/exdsq
0123      norm22=(zone+rbar22)*(zone+rbar22)/exdsq
0124      norm12=(zone+rbar11)*(zone+rbar22)/exdsq
0125      return
0126      end

```

```

0001      subroutine recvr(tlng,tclt,xtr,rho,rlng,rclt)
0002      c
0003      c      Returns coordinates of a point which is at a specified great
0004      c      circle distance and bearing angle from the input point
0005      c
0006      c      Input: TLNG is longitude of transmitter
0007      c              TCLT is co-latitude of transmitter
0008      c              XTR  is geographic bearing angle of receiver
0009      c              RHO  is great circle distance to the receiver
0010      c
0011      c      Output: RLNG is longitude of receiver
0012      c              RCLT is co-latitude of receiver
0013      c
0014      c      All coordinates, RHO and XTR are in radians
0015      c      Sign convention is + for West and North
0016      c
0017      data pi/3.14159265e0/,twopi/6.28318531e0/
0018      c
0019      reduce(arg)=sign(amin1(abs(arg),1.),arg)
0020      c
0021      ctclt=cos(tclt)
0022      stclt=sin(tclt)
0023      br=xtr
0024      gcd=rho
0025      c
0026      if(abs(br) .lt. twopi) go to 2
0027      br=amod(br,twopi)
0028      2   if(br .ge. 0.) go to 3
0029      br=br+twopi
0030      3   if(gcd .lt. pi) go to 5
0031      gcd=twopi-gcd
0032      br=br+pi
0033      if(br .ge. twopi) br=br-twopi
0034      5   if(br .le. 1.e-6) go to 10
0035      if(abs(br-pi) .le. 1.e-6) go to 14
0036      if(abs(gcd-pi) .le. 1.e-6) go to 14
0037      cgcd=cos(gcd)
0038      sgcd=sin(gcd)
0039      crclt=ctclt*cgcd+stclt*sgcd*cos(br)
0040      srclt=sqrt(1.-crclt**2)
0041      rclt=acos(reduce(crclt))
0042      delta=acos(reduce((cgcd-ctclt*crclt)/(stclt*srclt)))
0043      if(br .lt. pi) delta=-delta
0044      rlng=tlng+delta
0045      go to 20
0046      c
0047      c      receiver is due north, south or on opposite longitude
0048      10  rclt=tclt-gcd
0049      if(rclt .lt. 0.) go to 12
0050      11  rlng=tlng
0051      crclt=cos(rclt)
0052      srclt=sin(rclt)
0053      go to 99
0054      12  rclt=-rclt
0055      13  rlng=tlng+pi
0056      crclt=cos(rclt)
0057      srclt=sin(rclt)

```

# RECVR

```

0058      go to 20
0059      14      rclt=tclt+gcd
0060              if(rclt .lt. pi) go to 11
0061              rclt=twopi-rclt
0062              go to 13
0063      c
0064      20      if(rlng .gt. pi) go to 21
0065              if(rlng .lt. -pi) go to 22
0066              go to 99
0067      21      rlng=rlng-twopi
0068              go to 99
0069      22      rlng=rlng+twopi
0070      c
0071      99      return
0072              end

```

```

0001      subroutine rplynm
0002      implicit real *8 (a-h,o-z)
0003      c
0004      include 'common2.for'
0018      include 'common3.for'
0043      c
0044      complex*16 lgmtrx(30,4),prod,tlist1,tlist2
0045      complex*8 stheta
0046      real*4 dst(30)
0047      integer use(30)
0048      c
0049      m=1
0050      10  if(m le 30 and tlist(1,m) .gt. 0) then
0051          theta=tlist(1,m)
0052          theta=tlist(2,m)
0053          c=cdcos(theta+zdtr)
0054          csq=c*c
0055          s=cds n(theta+zdtr)
0056          ssq=s*s
0057          call nteg
0058          do 12 n=1,4
0059      12  lgmtrx(m,n)=logrs(n)
0060          adjflg=1
0061          m=m+1
0062          go to 10
0063      end if
0064      imax=m-1
0065      if(imax le 1) then
0066          print *, 'ERROR RPLYNM  Insufficient tlist'
0067          stop
0068      else
0069          jmax=min0(imax,nrtlist)
0070          adjflg=0
0071          return
0072      end if
0073      c
0074      entry uspoly
0075      c      Distance from theta to tlist angles
0076      stheta=theta
0077      do 24 i=1, jmax
0078          use(i)=1
0079      24  dst(i)=sqrt((real(stheta-tlist(1,i))**2+
0080      &      (aimag(stheta)-tlist(2,i))**2)
0081      c      Order tlist angles according to distance
0082      call sortr(dst,jmax,use(jmax,1),jmax)
0083      c      Use only nrtlist angles
0084      do 50 n=1,4
0085          logrs(n)=0
0086      do 45 i=1, jmax
0087          i=use(i)
0088          tlist1=dcmplx(dble(tlist(1,i)),dble(tlist(2,i)))
0089          prod=zone
0090      do 44 j=1, jmax
0091          j=use(j)
0092          if(j ne 2) then
0093              tlist2=dcmplx(dble(tlist(1,j)),dble(tlist(2,j)))
0094              prod=prod*(theta-tlist2)/(tlist1-tlist2)

```



RPLYNM

```
0095      end if
0096      44      continue
0097      45      logrs(n)=logrs(n)+prod*lgmtrx(i1,n)
0098      50      rs(n)=cdexp(logrs(n))
0099      return
0100      end
```

```

0001      subroutine savemc
0002      c
0003      c      This routine writes the mode parameters out to the logical unit
0004      c      defined by LUNIT7.
0005      c
0006      include 'common1.for'
0022      include 'common2.for'
0036      c
0037      write(lunit7,100) rho,freq,azim,codip,magfld,sigma,epsr,hprout
0038      do 10 m=1,modes
0039      10  write(lunit7,101) tp(m),nterm(m),t term(1,m),t term(2,m),
0040      $      tp(m),nterm(m),t term(3,m),t term(4,m)
0041      write(lunit7,102)
0042      return
0043      c
0044      100  format('r',f7.3,' f',f8.4,' a',f8.3,' c',f8.3,' m',e10.3,
0045      $      ' s',1pe10.3,' e',0pf5.1,' t',f5.1)
0046      101  format('1',0p2f9.5,i1,1p4e15.8/'2',0p2f9.5,i1,1p4e15.8)
0047      102  format(' ')
0048      end

```

```

0001      subroutine sortr(array,nra,index,nri,ii,jj)
0002      c
0003      c      algorithm 347,r.c.singleton,communications of the acm,v12,n3,may69
0004      c      sorts array into order of increasing value, from index ii to jj
0005      c      also orders index simultaneously if nri gt 1
0006      c      the only arithmetic operation on array is subtraction
0007      c      the user should consider the possibility of integer overflow
0008      c      arrays iu(k) and il(k) permit sorting up to 2**(k+1)-1 elements
0009      c
0010      dimension array(1),index(1),iu(36),il(36)
0011      if(jj .gt. nra) print *, 'warning from sortr:  jj gt nra'
0012      m=1
0013      i=ii
0014      j=jj
0015      5      if(i .ge. j) go to 70
0016      10      k=i
0017      ij=(i+j)/2
0018      t=array(ij)
0019      if(nri .le. 1) go to 15
0020      n=index(ij)
0021      15      if(array(i) .le. t) go to 20
0022      array(ij)=array(i)
0023      array(i)=t
0024      t=array(ij)
0025      if(nri .le. 1) go to 20
0026      index(ij)=index(i)
0027      index(i)=n
0028      n=index(ij)
0029      20      l=j
0030      if(array(j) .ge. t) go to 40
0031      array(ij)=array(j)
0032      array(j)=t
0033      t=array(ij)
0034      if(nri .le. 1) go to 25
0035      index(ij)=index(j)
0036      index(j)=n
0037      n=index(ij)
0038      25      if(array(i) .le. t) go to 40
0039      array(ij)=array(i)
0040      array(i)=t
0041      t=array(ij)
0042      if(nri .le. 1) go to 40
0043      index(ij)=index(i)
0044      index(i)=n
0045      n=index(ij)
0046      go to 40
0047      30      array(l)=array(k)
0048      array(k)=tt
0049      if(nri .le. 1) go to 40
0050      index(l)=index(k)
0051      index(k)=nn
0052      40      l=l-1
0053      if(array(l) .gt. t) go to 40
0054      tt=array(l)
0055      if(nri .le. 1) go to 50
0056      nn=index(l)
0057      50      k=k+1

```

# SORTR

```

0058      if(array(k) .lt. t) go to 50
0059      if(k .le. 1) go to 30
0060      if(1-i .le. j-k) go to 60
0061      il(m)=i
0062      iu(m)=l
0063      i=k
0064      m=m+1
0065      go to 80
0066  60      il(m)=k
0067          iu(m)=j
0068          j=l
0069          m=m+1
0070          go to 80
0071  70      m=m-1
0072          if(m .eq. 0) return
0073          i=il(m)
0074          j=iu(m)
0075  80      if(j-i .ge. 11) go to 10
0076          if(i .eq. ii) go to 5
0077          i=i-1
0078  90      i=i+1
0079          if(i .eq. j) go to 70
0080          t=array(i+1)
0081          if(nri .le. 1) go to 95
0082          n=index(i+1)
0083  95      if(array(i) .le. t) go to 90
0084          k=i
0085  100     array(k+1)=array(k)
0086          if(nri .le. 1) go to 105
0087          index(k+1)=index(k)
0088  105     k=k-1
0089          if(t .lt. array(k)) go to 100
0090          array(k+1)=t
0091          if(nri .le. 1) go to 90
0092          index(k+1)=n
0093          go to 90
0094          end

```

```

0001      subroutine wvguid
0002      c
0003      c      This routine drives the generation of mode parameters using the
0004      c      input elist.
0005      c      If RPOLY is 0, then all calculations are made exactly.
0006      c      If RPOLY is 2, then all calculations are made approximately using
0007      c      the routine RPLYNM.
0008      c      If RPOLY is 1, then the initial calculations are approximate to
0009      c      refine the initial solutions and the final solutions are obtained
0010      c      using the exact formulation.
0011      c
0012      include 'common1.for/list'
0013      1 c
0014      1 common/input/freq,rho,azim,codip,magfld,sigma,epsr,beta,hprime,
0015      1 $      hprout
0016      1 common/path/pathid,tlong,tlat,rlong,rlat,rbear,dmax,drmin,drmax,
0017      1 $      year,month,day,gmt,nprint,nprof,npath,igcd,ignd,mdir,lost,
0018      1 $      lunit7,lx
0019      1 common/ionosp/htlist(50),lnlist(50,3),hcllist(50),cflist(50,3),
0020      1 $      charge(3),mratio(3),nrspec,lhtmx,lhtmn,lht,mhtmx,mhtmn,mht
0021      1 c
0022      1 character*80 pathid
0023      1 integer year,day
0024      1 real*4 freq,rho,azim,codip,magfld,sigma,epsr,beta,hprime,hprout,
0025      1 $      tlong,tlat,rlong,rlat,rbear,dmax,drmin,drmax,gmt,
0026      1 $      htlist,lnlist,hcllist,cflist,charge,mratio
0027      1 c
0028      include 'common2.for/list'
0029      1 c
0030      1 common/wg in/elist(2,30),tlist(2,30),dtheta(2),lub(2),deigen(2),
0031      1 $      thtinc,ftol,maxitr,alpha,h,d,prec,wr0,atnmax,debug,typitr,
0032      1 $      rpoly,nrtlst
0033      1 common/wg out/tp(30),tterm(4,30),nterm(30),mode(30),modes,nmds
0034      1 c
0035      1 complex*8 tp,tterm,dthta
0036      1 integer debug,typitr,rpoly
0037      1 real*4 elist,tlist,dtheta,lub,deigen,thtinc,ftol,alpha,h,d,prec,
0038      1 $      wr0,atnmax
0039      1 c
0040      1 equivalence (dtheta,dthta)
0041      1 c
0042      include 'common3.for/list'
0043      1 c
0044      1 common/f fcn/omega,wn,thetar,thetar,c,s,csq,ssq,f,dfdtht,
0045      1 $      hg,norm11,norm22,norm12,rbar11,rbar22,
0046      1 $      nriter,newq,adjflg,isotrp
0047      1 common/r matrx/r11,r22,r12,r21,
0048      1 $      logr11,logr22,logr12,logr21,
0049      1 $      dl1ldh,dl22dh,dl12dh,dl2ldh,ht,delh,topht
0050      1 common/m matrx/m11,m12,m13,m21,m22,m23,m31,m32,m33
0051      1 c
0052      1 integer adjflg
0053      1 real*8 omega,wn,thetar,thetar,ht,delh,topht,r(8),logr(8),dlrdh(8)
0054      1 complex*16 thetar,c,s,csq,ssq,f,dfdtht,
0055      1 $      hg,norm11,norm22,norm12,rbar11,rbar22,
0056      1 $      r11,r22,r12,r21,rs(4),
0057      1 $      logr11,logr22,logr12,logr21,logrs(4),

```

## WVGUID

```

0058 1 $      dl11dh,dl22dh,dl12dh,dl21dh,d1rsdh(4),
0059 1 $      m11,m12,m13,m21,m22,m23,m31,m32,m33,
0060 1 $      zero/(0.d0,0.d0)/,zone/(1.d0,0.d0)/,
0061 1 $      zmplxi/(0.d0,1.d0)/,zdtr/(1.745329252d-2,0.d0)/
0062 1 c
0063 1      equivalence (thetar,theta),
0064 1 $      (r11,rs),(logr11,logrs),(dl11dh,d1rsdh),
0065 1 $      (r11,r),(logr11,logr),(dl11dh,d1rdh)
0066 1 c
0067 c
0068      complex*16 theta0,stp, ratio,store1,store2,store3,
0069 $      wterm,ecomp,mik
0070      complex* 8 eigen(30)
0071      real*8 cdang,reflht,capk,stpr,stpi
0072      integer psave
0073      character*20 reason,blank
0074      equivalence (elist,eigen)
0075      data blank/'      '/,reflht/70.d0/
0076 c
0077      psave=rpoly
0078      capk=1/(1-.5*alpha*h)
0079      omega=6.283185306d3*freq
0080      wn=2.0958426d-2*freq
0081      wterm=dcmplx(0.d0,-.5d0*wn*reflht)
0082      mik=dcmplx(0.d0,-1.d3*wn)
0083      debug=nprint
0084      adjflg=0
0085      newq=0
0086      if(magfld.le. 1.e-10) then
0087          isotrp=1
0088      else
0089          if(codip.eq.90. and. (azim.eq.90. or. azim.eq.270.)) then
0090              isotrp=2
0091          else
0092              isotrp=0
0093          end if
0094      end if
0095      call intcmp
0096      if(rpoly.eq. 1) call rplynm
0097      if(nprint.gt. 0) print 1010
0098 10      kn=0
0099      ms=0
0100      index=1
0101 13      if(elist(1,index).eq. 0.) go to 62
0102          theta0=eigen(index)
0103          kn=kn+1
0104          ms=ms+1
0105          mn=mode(kn)
0106          reason=blank
0107 15      theta=theta0
0108          call iterat
0109          fmag=cfabs(f)
0110          if(nriter.ge.maxitr and fmag.gt.ftol) then
0111              write(reason,2000) fmag
0112              go to 50
0113          end if
0114          pmag=cfabs(rbar11*r12/(zone-rbar11*r11))

```

## WVGUID

```

0115      thtr=thetar
0116      thti=thetai
0117      if(thti .ge. 0.) then
0118          write(reason,2001)
0119          go to 50
0120      end if
0121      if(kn .gt. 1) then
0122          do 30 kd=1,kn-1
0123              if(abs(thtr-elst(1,kd)) .gt. deigen(1)) go to 30
0124              if(abs(thti-elst(2,kd)) .gt. deigen(2)) go to 30
0125              write(reason,2002) kd
0126              go to 50
0127      30      continue
0128      end if
0129      eigen(kn)=theta
0130      33      if(ms .eq. mn) go to 35
0131              if(rpoly .eq. 0 .and. nprint .gt. 0) print 1003
0132              ms=ms+1
0133              go to 33
0134      35      if(rpoly .eq. 1) go to 60
0135      c
0136          if(nriter .gt. maxitr/2) then
0137              print *, 'Warning WVG: Excessive iterations for this mode:'
0138              lost=2
0139          end if
0140          s=cdsin(theta*zdtr)
0141          stp=s*capk
0142          at=-8.6858896d3*wn*dimag(stp)
0143          vc=1.d0/dreal(stp)
0144          tp(mn)=-zmplxi*cdlog(cdsqrt(zone-stp*stp)+zmplxi*stp)/zdtr
0145      c
0146          ratio=cdsqrt(s)/(dfdtht/zdtr)
0147          store1=(zone+rbar11)**2*(zone-rbar22*r22)*ratio/rbar11
0148          store2=(zone+rbar11)*(zone+rbar22)*ratio
0149          store3=(zone+rbar22)**2*(zone-rbar11*r11)*ratio/rbar22
0150          ecomp=wterm*store1*(s*hg)**2
0151          wm=20.d0*dlog10(cdabs(ecomp))
0152          wa=cdang(ecomp)
0153          if(nprint .gt. 0) print 1011,theta0,mn,nriter,eigen(kn),fmag,
0154          $              pmag,at,vc,wm,wa,tp(mn)
0155      c
0156          t term(1,mn)=store1/norm11
0157          t term(2,mn)=store3/norm22
0158          t term(3,mn)=store2/norm12*r21
0159          t term(4,mn)=r12/r21
0160          if(cdabs(zone-r11*rbar11) .ge. cdabs(zone-r22*rbar22)) then
0161              nterm(mn)=2
0162          else
0163              nterm(mn)=1
0164          end if
0165          go to 60
0166      c
0167      50      if(rpoly .eq. 1) go to 63
0168              if(nprint .gt. 0) print 1012,theta0,nriter,theta,fmag,pmag
0169              if(rho .eq. 0 .or. npath .eq. 1) then
0170                  if(rpoly .eq. 1) go to 63
0171      c          OK to drop a mode at the transmitter

```

# WVGUID

```

0172         if(kn .eq. 30 .or. index .eq. 30) then
0173             kn=kn-1
0174             go to 62
0175         end if
0176         do 53 m=kn,30
0177     53     eigen(m)=eigen(m+1)
0178             eigen(30)=(0.,0.)
0179             go to 13
0180         else
0181             print *, 'ERROR WVG:  Lost mode',mn,' because ',reason
0182             lost=1
0183             go to 999
0184         end if
0185     c
0186     60     if(kn .eq. 30 .or. index .eq. 30) go to 62
0187             index=index+1
0188             go to 13
0189     62     nmde=kn
0190             eigen(nmde+1)=(0.,0.)
0191             if(nmde .eq. 0) go to 65
0192             if(rpoly .ne. 1) go to 999
0193     63     rpoly=0
0194             go to 10
0195     65     print *, 'ERROR WVG:  Lost all modes'
0196             lost=1
0197     c
0198     999     if(nprint .gt. 0) print 1003
0199             rpoly=psave
0200             return
0201     c
0202     1003    format(' ')
0203     1010    format(/5x,'initial',4x,'mode iter',6x,'eigen',8x,'mag f',5x,
0204             $      'mag p',5x,'atten',4x,'v/c',8x,'wait''s exc',8x,'theta''')
0205     1011    format(1x,2f7.3,i4,i5,2x,2f7.3,2(1x,1pe9.3),1x,0pf8.3,1x,f9.5,
0206             $      1x,f9.3,1x,f6.3,1x,2f8.3)
0207     1012    format(1x,2f7.3,4x,i5,2x,2f7.3,2(1x,1pe9.3))
0208     2000    format('fmag=',1pe8.2)
0209     2001    format('thetai .gt. 0.')
0210     2002    format('it matches mode',i3)
0211         end

```



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